SYSTEMS ENGINEERING
Research Center

Atlas: The Theory of Effective Systems Engineers, Version 0.5

Technical Report SERC-2015-TR-108

December 1, 2015

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Stevens Institute of Technology

Work conducted under Research Topic 135

Contract No. HQ0034-13-D-0004 Task Order 0035, RT 135

The Systems Engineering Research Center (SERC) is a federally funded University Affiliated Research Center managed by Stevens Institute of Technology.

This material is based upon work supported, in whole or in part, by the U.S. Department of Defense through the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) under Contracts H98230-08-D-0171 and HQ0034-13-D-0004.

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ACKNOWLEDGEMENTS

The Helix team would like to thank all the organizations and individuals that willingly participated in the project, offering their resources, time and effort that were indispensible to our research. Their active participation in the Helix interviews provided us data that was rich in both quality and quantity, which we hope makes this research valuable and useful to the participating organizations and the systems engineering community at large.

We are most grateful to the Office of the Deputy Assistant Secretary of Defense for Systems Engineering (DASD(SE)), especially Kristen Baldwin and Scott Lucero, for their continued support, without which this research would not be possible. The National Defense Industrial Association Systems Engineering Division (NDIA-SED) and the International Council on Systems Engineering (INCOSE) are both valued partners in this research and we thank them, especially Don Gelosh, Courtney Wright, David Long, and Bill Miller.

We also thank all former members of the Helix research team whose contributions have shaped our research over the years.

- The Helix Team

Executive Summary

Research conducted through the Helix project has now produced version 0.5 of *Atlas*[1]: the *Theory of Effective Systems Engineers.* Figure 1 provides an overview of the theory and its various elements.

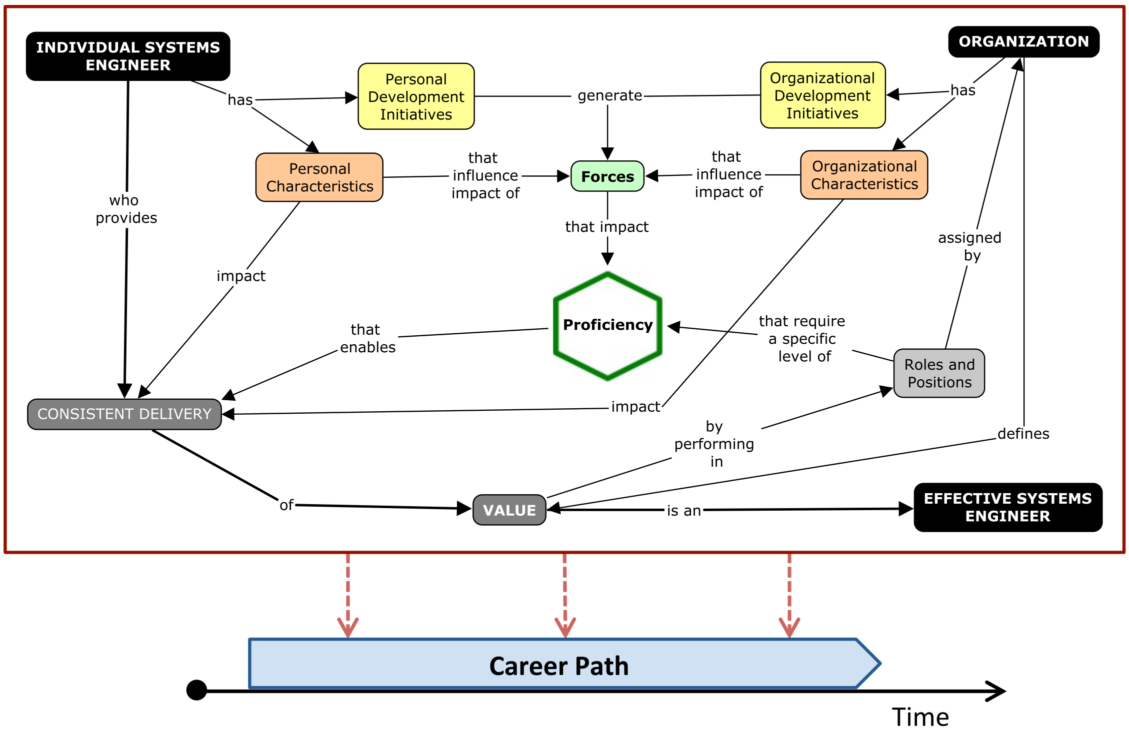


Figure 1. *Atlas*: *The Theory of Effective Systems Engineers*

Foundational to *Atlas* is the understanding that an effective systems engineer is someone who consistently delivers value by performing systems engineering activities in positions assigned by the organization, as illustrated in Figure 1 along with the elements that influence and enable this effectiveness of systems engineers. The changes in these elements over time present a dynamic view, that is manifested in the career paths of systems engineers.

This report presents details of the various elements of *Atlas*; provides insights into how they were built based on Helix data; and offers recommendations for the development of effective systems engineers by individuals and organizations.

The Helix team continues to develop *Atlas* into a complete and mature theory that may be deployed independently by individuals developing their personal careers in systems engineering and by organizations developing their systems engineering workforce.

[1] In Greek mythology, Atlas held the world on his shoulders and many of the systems engineers who were interviewed felt they held the project on their shoulders. Also, as a collection of maps or pathways or directions, the term "atlas".

PART 1

BACKGROUND AND INTRODUCTION

The US Department of Defense (DoD) and the Defense Industrial Base (DIB) – contractors that develop and deliver systems to the DoD – have been facing major systems engineering challenges in recent years (e.g. GAO 2008, 2011, 2012, 2013). Mission requirements are evolving and they demand ever more sophisticated and complex systems (e.g. Boehm et al. 2010; INCOSE Technical Operations 2007; Davidz 2006; Davidz and Nightingale 2007; Frank et al. 2007; INCOSE 2014); the tools, processes, and technologies that systems engineers must master keep changing more rapidly (e.g. Frank 2006); and budgets and schedules are being compressed dramatically. An additional concern is that thousands of systems engineers in the defense workforce are nearing retirement; they will take with them hundreds of thousands of staff-years of experience (DoD 2013).

Organizations have responded to these challenges in a variety of ways, such as offering extended training and education to their current workforce or systematically seeking to select specialty engineers with the potential to become systems engineers and incorporating them into the ranks of systems engineers. Unknown is whether these actions are producing the desired results because there is no common understanding of the diverse roles that systems engineers play, how they are selected and evaluated, what competencies are most important for different roles, how to evaluate effectiveness, or how experiences impact effectiveness. These and many other insights will be critical to maintaining and growing the systems engineering workforce in the US DoD and DIB.

Sections in Part 1 provide the necessary background and introductions to the Helix project and to *Atlas: The Theory of Effective Systems Engineers*:

- Section 1 introduces the Helix project;
- Section 1 presents the overall structure of this report;
- Section 3 discusses the Helix research approach;
- Section 4 discusses the data used in the Helix project;
- Section 5 presents the concept of 'effectiveness' and 'value' that are foundational to the development of *Atlas*; and
- Section 6 introduces *Atlas: The Theory of Effective Systems Engineers*.

1 INTRODUCTION TO THE REPORT

This technical report is written as a standalone document, presenting version 0.5 of *Atlas: The Theory of Effective Systems Engineers*. Several earlier published Helix papers and technical reports are referred to throughout this report. However, the reader is not required to read the earlier technical report describing *Atlas 0.25* that was published in 2014 or any of the other Helix papers or reports, in order to understand *Atlas 0.5.*

The report is divided into five major Parts, each including a number of sections:

- Part 1 presents the necessary background and introduction to the Helix project and to *Atlas*.
- Part 2 discusses the various elements that constitute *Atlas*.
- Part 3 describes the data and insights from data analysis that contributed to the development of *Atlas*.
- Part 4 discusses the career paths of systems engineers and introduces some ways in which individuals and organizations may use *Atlas* for personal career development and for systems engineering workforce development.
- Part 5 concludes the report by summarizing the key recommendations and describing the proposed future plans for the Helix project.

Readers should note the following about the report:

- Throughout the report, the term 'Helix' is used to denote either the project or the team that performed the work in developing *Atlas*.
- The *Guide to the Systems Engineering Body of Knowledge* (SEBoK) is used across the report as the primary source of consistent terminology and definitions relevant to systems engineering. (BKCASE Editorial Board 2015)
- All insights and observations are presented only in an anonymous, aggregated manner. Individual systems engineers or organizations that participated in the Helix project are neither named nor are they identifiable from this report.

2 The Helix Project

The Systems Engineering Research Center (SERC), a University Affiliated Research Center (UARC), set up by the U.S. Department of Defense (DoD), responded to the systems engineering workforce challenges by initiating the Helix Project to investigate the "DNA" of systems engineers, beginning with those who work in defense and then more broadly. The US Deputy Assistant Secretary of Defense for Systems Engineering (DASD(SE)), the International Council on Systems Engineering (INCOSE) and the Systems Engineering Division of the National Defense Industrial Association (NDIA-SED) jointly sponsor Helix. To ensure Helix delivers the greatest value and to help Helix obtain access to the necessary data, Helix formed the Helix Advisory Panel (HAP) with representatives primarily from those three sponsor organizations, and has held two annual workshops with a broad set of representatives from across the government, academia, and industry.

Helix is a multi-year longitudinal research project, which began gathering data from many organizations with DoD and the Defense Industrial Base (DIB) through a combination of techniques, including interviews with hundreds of systems engineers. In 2014, Helix began to reach beyond DoD and the DIB, to gather data from other types of organizations as well, including non-defense organizations in the US and non-US organizations. Version 0.25 of *Atlas* was also published in 2014. *Atlas* identifies the key variables that impact a systems engineer's effectiveness – positively or negatively – and provides, as much as possible, details on how these variables impact effectiveness.

During 2015, Helix expanded its data collection by conducting interviews with non-DoD organizations as well; matured *Atlas* into the next version, *Atlas 0.5*; defined and analyzed the career paths of systems engineers; and did implementation trials of *Atlas*. Discussions on these topics are included in this report.

3 HELIX RESEARCH APPROACH

With an objective to respond to the systems engineering workforce related needs of the sponsors and other systems engineering organizations that wish to derive value from this project, Helix is focusing on three main research questions:

1. What are the characteristics of systems engineers?
2. How effective are systems engineers and why?
3. What are employers doing to improve the effectiveness of their systems engineers?

These three research questions, established at the start of the Helix project in 2012, continue to guide the Helix research process and various research related decisions.

3.1 HELIX RESEARCH METHODOLOGY

The research methodology adopted for Helix research may be considered to be a modified grounded theory based approach, employing qualitative and quantitative research methods.

During 2013 and 2014, Helix primarily focused on data collection from DoD and DIB organizations through semi-structured in-person interviews with individuals or small groups, continually refining the interview questions and process. Follow-up interviews were conducted by telephone with most of the participants. Analysis of the data to address the Helix research questions offered insights into the effectiveness of systems engineers and led to the development of an early version of *Atlas* that was published in November 2014. During 2015, data collection was expanded to organizations outside of DoD and DIB, and *Atlas 0.25* was validated and improved upon, leading to the next version, *Atlas 0.5*, published in this report.

The Helix project adopted a grounded theory approach because it did not presuppose any specific theory or propose any hypotheses at the start of the project. Grounded theory was developed in the social sciences as a method for developing theory that is grounded in data that is systematically gathered and analyzed (Goulding 2002). Rather than beginning with a hypothesis, the first step was data collection. This approach is unusual in engineering research, where a researcher traditionally begins with a theoretical framework that he or she applies to the phenomenon to be studied. In the Helix project, the data collected from the many semi-structured interviews were marked up with codes that were grouped into concepts, that led to the identification of constructs and categories that formed the building blocks of *Atlas*. This approach minimized any bias that might be introduced by the researchers, instead allowing the large data set collected through the Helix project to drive theory development. Having established a preliminary theory of effective system engineers and proficiency model of systems engineers, data collection and interviews conducted during 2015 focused on validating *Atlas*, and refining the theory towards developing *Atlas 1.0* in 2016.

Qualitative research aims to create or discover what things are made of, and what is created or discovered are called constructs. Qualitative research is useful for obtaining insight into situations and problems on which one has little knowledge a priori. This method is commonly used for providing in-depth descriptions of procedures, beliefs and knowledge, including the opinions of respondents about particular issues; detailed data is gathered through open-ended questions. Data collection for the Helix project and subsequent analysis of the data was primarily done employing qualitative research methods; appropriate software tools were used to support coding and identification of constructs.

Quantitative research begins once initial constructs are in hand. It attempts to gather data by objective methods to provide information about relations, comparisons, and predictions. In the context of the Helix project, quantitative research was performed once initial constructs for demographics of systems engineers, their organizations, and their career paths were established. Data was collected from their resumes, as well as through pointed questions during interviews. Quantitative analysis continues to be performed on various elements of *Atlas* that were developed based on qualitative research, particularly on the proficiency model.

3.2 Helix Research Process

The Helix research methodology discussed in the preceding section was deployed using the research process illustrated in Figure 2 below.

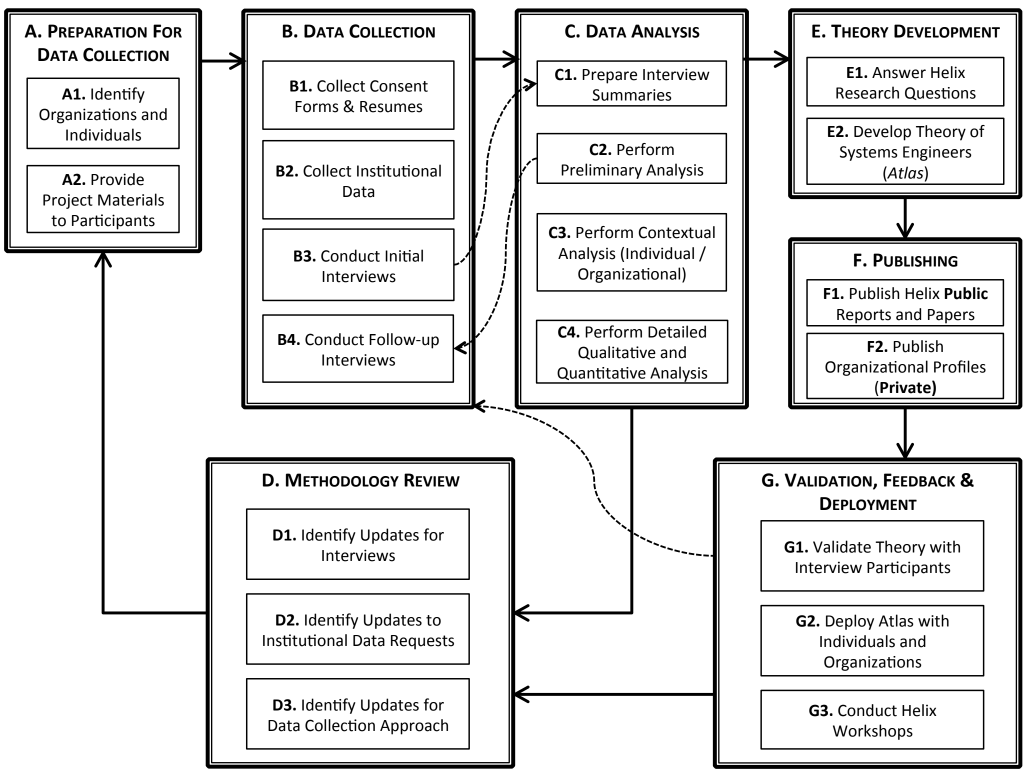


Figure 2. Helix Research Process

The Helix research process consists of seven major steps:

A. Preparation for Data Collection
B. Data Collection
C. Data Analysis

D. Methodology Review
E. Theory Development
F. Publishing
G. Validation, Feedback & Deployment

The focus of Helix in 2013 was on executing the loop **A-B-C-D-A** multiple times with different organizations. The loop **B-C-B** was executed a few times when follow-up interviews were conducted with some organizations. During 2014, in addition to performing the **A-B-C-D-A** loop with new organizations, steps **E-F-G** were executed that led to initial the development of *Atlas 0.25*. In 2015, much effort was concentrated in executing step **G**, as well as executing the loop **A-B-C-D-A** with commercial non-DoD organizations as well as with many participants who did not consider themselves to be systems engineers. This has led to further refinement of Atlas in step **E**, leading to step **F** - the publishing of *Atlas 0.5* in this report.

3.2.1 Preparation for Data Collection (A)

Since Helix research is based on a grounded theory approach, preparation for data collection was the first step executed in the project. Initially, organizations from within the US DoD and other organizations from the DIB were identified for data collection; also, the primary focus was on systems engineers in these organizations (**A1**). As Helix progressed, in 2015 other commercial organizations from non-DoD sectors such as healthcare and information technology were identified for data collection. The latest reports and papers published from the Helix project were provided to potential interviewees (**A2**). Based on their willingness to participate in Helix interviews, the organization makes final decisions on who participates in Helix interviews.

3.2.2 Data Collection (B)

The first round of data collection with an organization is typically through a site visit to the organization, where in-person interviews are conducted. Typically, there will be 2 or 3 Helix interviewers and anywhere from 1 to 6 interviewees in a single 90-minute interview session (**B3**). Following approved research protocols, a signed consent form is collected from the participants before conducting interviews; resumes are also requested from all participants (**B1**). Any available organizational data that will provide insights into the systems engineers in the organization and how they are structured within the organization are gathered before and during the site visit (**B2**). In 2015, as the project expanded to include non-DoD participants, initial interviews were conducted over telephone when the number of participants from an organization was very low. All follow-up interviews were conducted over telephone (**B4**).

3.2.3 Data Analysis (C)

The first step in data analysis is to prepare summaries of all interview sessions (**C1**). Where interviewees permit audio recording, transcripts are first created then cleaned and prepared for further analysis. If recording is not permitted, summaries are created from the notes taken during the interviews. Preliminary analysis, typically not employing significant effort on using analysis tools, is performed to quickly identify additional questions to be asked or additional data to be collected during follow-up interviews (**C2**). Since 2014, significant research effort has been put into performing contextual analysis on an individual, particularly on her career path (**C3**). Detailed qualitative and quantitative analyses, using software tools as necessary, have been performed on the large amounts of data that have been collected through Helix interviews (**C4**). These analyses make significant contributions to theory development efforts (**F**).

3.2.4 METHODOLOGY REVIEW (D)

Data collection and analysis is being performed iteratively, as Helix continues to identify and visit organizations. After any site visit and before the next one, a review is conducted to identify any updates to the interview questions or process (**D1**). While much organizational data is desired for Helix analysis, not all information is being made available within an organization in a form that may be readily shared with Helix researchers. Based on experiences with organizations, the nature and content of organizational data requested has been regularly updated (**D2**). Based on significant data analysis and theory development that was performed in 2014, the data collection approach has largely been revised from being a semi-structured interview to being a discussion on assessing the proficiencies of individuals and analyzing their career paths (**D3**). Feedback received from individuals and organizations on the Helix reports (**G**) also influenced the updates performed in step **D**.

3.2.5 THEORY DEVELOPMENT (E)

Analysis performed on data collection during 2013 focused primarily on answering the Helix research questions at a broad level (**E1**). Since 2014, the focus of analysis has been to develop *Atlas* (**E2**). Version 0.25 of *Atlas* was published in November 2014, and the next version, *Atlas 0.5*, is being published in this report. Refining this theory, and packaging it for independent assessment and deployment by individuals and organizations will be the focus of research efforts in 2016.

3.2.6 PUBLISHING (F)

Publishing reports and papers for public consumption is a key objective for Helix research (**F1**). A technical report was published in 2013, and *Atlas 0.25* was published in 2014. All results and observations reported in Helix publishing are done in an anonymous aggregated manner. Nothing published by Helix is traceable to any particular individual or to an organization. Organizations may choose to reveal their participation in the Helix project, but they are not listed in any Helix report. In addition, peer-reviewed conference and journal papers continue to be published for wide dissemination of Helix results. While some form of an organizational profile is created as part of internal Helix analysis, in some rare cases, a private report is provided to participating organizations upon request to support their systems engineering workforce development efforts (**F2**).

3.2.7 VALIDATION, FEEDBACK & DEPLOYMENT (G)

Since publishing *Atlas 0.25*, step **G** has become a critical step in the Helix process. In the interviews conducted in 2015, the *Atlas* theory and proficiency model have been validated in a number of ways (**G1**). Helix interviews are generally no longer limited to data collection only. During 2015, Helix has also begun deploying *Atlas* with specific organizations in an attempt to use *Atlas* to establish the proficiency levels and career paths of participants and to be able to discuss ways to develop their careers in the future, towards achieving targeted levels of proficiencies required for particular senior positions within the organization (**G2**). The first Helix workshop was held in July 2014, with participation of representatives from DoD, academia, and industry, including representatives from organizations that participated in Helix interviews. Feedback from the workshop significantly shaped *Atlas 0.25*. The second Helix workshop was held in August 2015 and reinforced the relevance and potential value of *Atlas* to a variety of systems engineering organizations (**G3**). A third Helix workshop is proposed for 2016 as well.

4 HELIX DATA

Helix research uses a bottom-up approach, based on the data being analyzed. Hence, it is essential to gather data that is sufficient in quantity and quality to enable effective development of *Atlas*, and to provide reliable insights and recommendations that can be confidently used for the development of effective systems engineers.

4.1 DATA SOURCES

The primary source of data for Helix research is face-to-face semi-structured interviews with participants at their place of work. Additional information about the participant and the organization were also collected as available. Another data source that Helix gained access to was the application data for the INCOSE Systems Engineering Professional (SEP) certification program.

4.1.1 HELIX INTERVIEW DATA

From June 2013, when Helix conducted its first site visit for data collection, until November 2015, a total of 289 participants were interviewed from 21 organizations. Typically, 2 to 3 members of the Helix team interviewed anywhere from 1 to 6 participants in a single interview session.

Interview participants, if willing, also provided their resumes with details about their educational background, work experiences, and any other information they wished to provide.

Follow-up interviews were conducted over telephone with willing participants, to explore topics that could not be covered in the initial face-to-face interviews or to collect additional information based on their resumes. Follow-up interviews were also used to validate results of Helix analysis.

In both the initial interviews as well as follow-up interviews, transcripts were created when audio recording was permitted; when not permitted, summaries were prepared from notes taken during the interviews. These transcripts and summaries from a total of about 270 hours of interviews form the bulk of data that Helix analyzed.

The data that was analyzed for *Atlas 0.5* and presented in this report is limited to a sub-set of interviewees from DoD and DIB organizations. Subsequent reports will include additional analysis performed on the Helix interview data.

4.1.2 INCOSE SEP APPLICATION DATA

INCOSE provides three different levels of SEP certification: Associate (ASEP), Certified (CSEP), and Expert (ESEP). Applicants from all over the world seeking INCOSE certification apply for the appropriate level based on their systems engineering experiences, knowledge, and accomplishment. INCOSE provided to Helix, under a Non-Disclosure Agreement, over 3000 application forms received from applicants during the period May 2004 to May 2014. Though the application data was available in electronic form, it was not in a format that would readily support analysis. Significant time and effort was spent in extraction, cleaning, and tabulating the data to enable further analysis.

Analysis of INCOSE data did not directly contribute to the building of *Atlas*, but provided some validation and additional insights for the analysis of the interview data.

4.2 DEMOGRAPHICS OF SAMPLE POPULATION

Understanding the sample population is important, since the interview data is reflective of the population from which it has been collected, and in turn, that data is the basis for *Atlas*. An understanding of the INCOSE applicants reveals the breadth of the data that it contains.

4.2.1 DEMOGRAPHICS OF INTERVIEW POPULATION

Among the 289 participants in Helix interviews, 80% were men and 20% were women. Though *Atlas* is about systems engineers, Helix also interviewed non-systems engineers who work with systems engineers in order to understand their perspectives on systems engineering and systems engineers. Within the systems engineers, their seniority as per criteria defined in Section 7.2 in Table 2 is illustrated below in Figure 3.

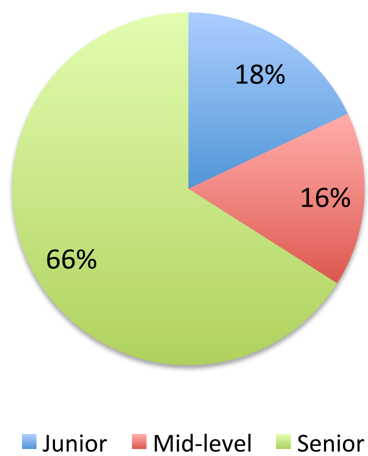


Figure 3. Seniority of Helix Interview Population

Among the 21 organizations that participated in Helix interviews, all the organizations visited by Helix in 2013 and 2014 belonged to either DoD or DIB. However, organizations representing other industry sectors such as healthcare and information technology were also visited in 2015.

It must be noted that due to the time required to create transcripts, prepare data for analysis, and to perform data analysis, some of the data collected from Helix interviews is not included in the analysis presented in this report. Quantitative results reported are based on analyses performed on all data collected through 2014 and on partial data collected in 2015. Data analysis will continue in 2016 and be reflected in subsequent technical reports and other publications.

4.2.2 DEMOGRAPHICS OF INCOSE SEP APPLICANTS

From the over 3000 application forms, about 2500 unique applicants were identified for further analysis. These applicants were predominantly from the U.S, but there were others from Asia and Europe as well, as indicated in Table 1.

Table 1. Geographical Distribution of INCOSE SEP Applicants

Rank	Country	# of Applicants	% of Total
1.	U.S.	1847	74%
2.	India	179	7%
3.	Germany	151	6%
4.	France	101	4%
5.	U.K.	49	2%
6.	Sweden	41	<2%
7.	Spain	36	1%
	Other	100	4%

Information from all the 2504 unique applicants was used for analysis of education background; a subset of those applicants was analyzed for experiences.

5 EFFECTIVENESS AND VALUE OF SYSTEMS ENGINEERS

The broad question that Helix is trying to address is: 'How to develop effective systems engineers?' The key term in this question, in addition to a consistent understanding of who is a systems engineer, is 'effective'. When initially asked who an 'effective systems engineer' was, interviewees tended to give the response '*one who develops (or supports development of) systems within time, cost, and schedule constraints*'. This definition was not found to be very insightful, and hence Helix defined an effective systems engineer as '*someone who consistently delivers value by performing systems engineering activities*'. This definition introduced the term 'value', and thus provided a context for the effectiveness. Of course, value by itself is a subjective term, and was not something that Helix wanted to define up front. Instead, Helix wanted to understand what systems engineers said was the value they provided and to understand what non-systems engineers said was the value that systems engineers provided.

The Helix team probed on the concept of value in 100% of the interviews conducted. The discussion of value took two general forms: an individual's perspective of the primary value that she provides as a systems engineer and an individual's perspective of the overarching value that systems engineers in her organization provide. Some individuals answered the value question in ways more readily linked with *proficiency* than value; for example, they might have referenced communication skills or deep understanding of the systems engineering processes. And as indicated above, a number of systems engineers also defined value in terms of overall project success ("on time, within budget"), which does not allow specific insights for systems engineers versus project managers or any other personnel who support the project. After filtering these types of responses, there were 313 individual excerpts on the value that systems engineers provide offered from 85 individual systems engineers.

The key values identified to date are provided in the list below. The main bullets state the overarching values that systems engineers provide; the sub-bullets are the ways these values are achieved, often discussed as enabling or lower-order values. Percentages reflect the percent of the data related to a given value or the relationship between values. So for example, the first value, "Keeping and maintaining the system vision", was described in 11% of the excerpts on value. However, in 39% of the areas where "Keeping and maintaining the system vision" was discussed, understanding of the customer's true requirements was described as a key enabling value. In some instances, percentages are not provided; these areas require additional analysis.

The primary values that systems engineers provide include:

- Keeping and maintaining the system vision (11%) is enabled by:
    - Getting the "true" requirements from the customer and creating alignment between the customer and the project team. (39%)
    - Seeing relationships between the disciplines and helping team members understand and respect those relationships. (33%)
    - Balancing technical risks and opportunities with the desired end result. (36%)
    - Providing the big picture perspective for the system. (44%)
- Enabling diverse teams to successfully develop systems. (10%)
    - Effectively understanding and communicating the system vision to the team, and ensuring that the team is aligned with this vision. (38%)
    - Helping the team to understand the big picture perspective and where they fit within

the larger picture. (38%)

    - Identifying areas of concern for integration in advance. (13%)

- Managing emergence in both the project and the system (7%)
    - Projecting into the future (14%), which includes staying “above the noise” of day-to-day development issues and identifying pitfalls.
    - Technical problem-solving balanced with the big picture perspective. (43%)
- Enabling good technical decisions at the system level (7%)
    - The ability to see the vision for the system and communicate that vision clearly is a key enabler to helping teams make good technical decisions. (40%)
    - The big picture perspective is critical for understanding the system holistically and enabling system-level technical decisions, versus decisions made at the component or sub-system level. (22%)
    - A systems engineer’s solid grasp on the customer’s needs is also a critical enabler to ensuring that decisions made will keep the system on the correct technical path. (22%)
    - Being able to bring together a diverse team of engineers and subject matter experts is also critically important. (26%)
    - A systems engineer’s problem solving abilities – particularly the ability to focus on root versus proximal cause – is also a key enabler. (26%).
- Supporting the business cases for systems (7%)
    - Balancing traditional project management concerns of cost and schedule with technical requirements. (41%)
    - Understanding the position of a system within the organization or customer’s portfolio and communicating this to the team. (59%)
- Translation of technical jargon into business or operational terms and vice versa (11%)
    - Translating highly technical information from subject matter experts into common language that other stakeholders can understand.
    - Translating operational concepts, customer needs, and customer desires into language that makes sense for engineers and program managers who do not have the same understanding of the systems’ future operating environment.

6 INTRODUCTION TO *ATLAS*

According to Merriam-Webster, a theory is a set of general principles or ideas relating to a particular subject (2014). *Atlas* is a set of general principles and ideas that relates to the subject of what makes systems engineers effective and why. In doing so, *Atlas* also provides insights into how individuals can develop into effective systems engineers throughout their careers and what organizations can do to support this development.

6.1 *ATLAS* OVERVIEW

The overview of *Atlas* in the context of an individual systems engineer employed in an organization is captured in the systemigram illustrated in Figure 4. A systemigram consists of nodes that contain noun phrases, links that contain verb phrases, and is to be read as sentences along the direction of the arrows. The primary sentence is read from the top left node to the bottom right node and presents the main theme of the systemigram. In the ensuing discussions, sentences to be read in the systemigram are italicized, where nodes are represented in square brackets.

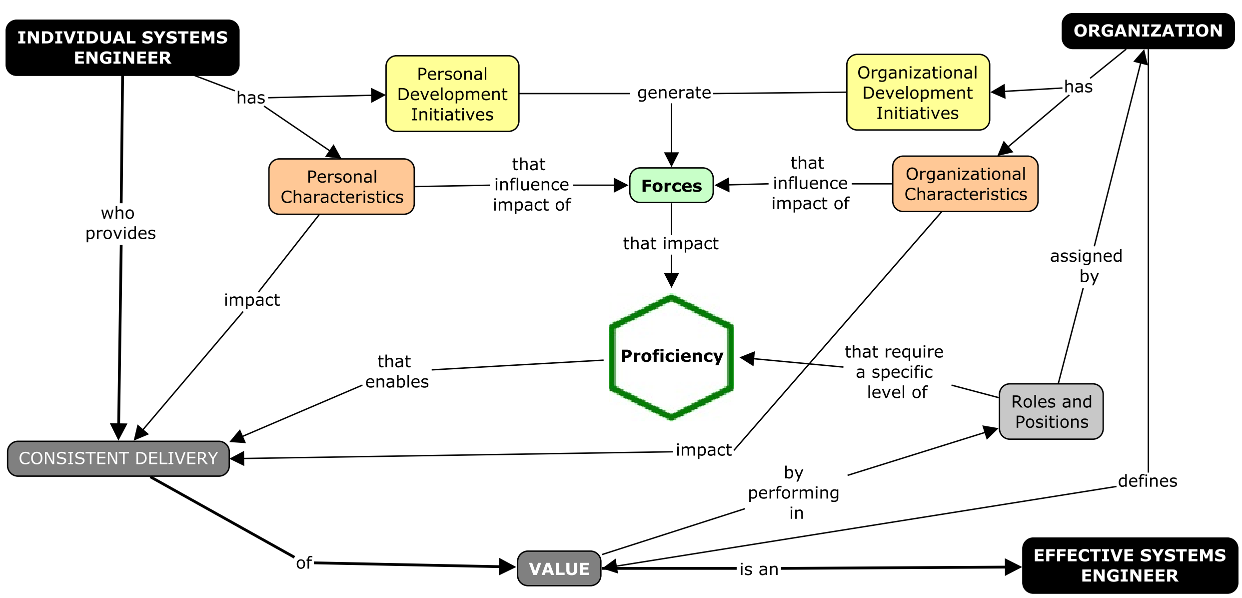


Figure 4. *Atlas* Overview

From Figure 4 above, it can be seen that the main theme of *Atlas* is: '*[Individual Systems Engineer] who provides [Consistent Delivery] of [Value] is an [Effective Systems Engineer]*'. This fundamental definition of an effective systems engineer hinges on *[Value]*, and it can be seen that '*[Organization] defines [Value]*'. Therefore, it is on the organization to define the value that the systems engineer is expected to provide. Further, the individual systems engineer provides '*[Value] by performing in [Roles and Positions] assigned by [Organization]*'. Therefore, it is again on the organization to establish the position of the systems engineer in terms of roles and responsibilities, keeping in mind that '*[Positions] require a specific level of [Proficiency] that enables [Consistent Delivery] of [Value]*'.

The core of *Atlas* is the proficiency of the individual systems engineer - what it is, and how it can be improved. '*[Individual Systems Engineer] has [Personal Development Initiatives]*' and '*[Organization] has [Organizational Development Initiatives]*'; together, they '*generate [Forces] that impact [Proficiency]*'. At the same time, '*[Individual Systems Engineer] has [Personal Characteristics] that influence the impact of [Forces]' and '[Organization] has [Organizational Characteristics] that influence the impact of [Forces]'* – these forces may have a positive or a negative influence. Further, both personal enabling characteristics and organizational characteristics '*impact [Consistent Delivery] of [Value]*'; again, the impact can be positive or negative. Amidst all these influences and impacts, the challenge for the individual systems engineer and the organization is to improve the '*[Proficiency] that enables [Consistent Delivery] of [Value]*' to the organization.

6.2 DYNAMIC ASPECT OF *ATLAS*

The *Atlas* overview illustrated in Figure 4 can be considered as a quasi-static snapshot in time, but many of the elements of *Atlas* are dynamic in nature. The level of proficiency of an individual systems engineer is not fixed, but is constantly changing due to the impact of forces over time. Similarly, other elements of *Atlas*, including characteristics and initiatives of the individual systems engineer and of the organization, continue to change over time. Further, as the level of proficiency of an individual systems engineer increases over time, the organization is likely to place that systems engineer into different positions.

This dynamic aspect of *Atlas* is not captured in the overview, but is reflected in the career paths of individuals over time, as illustrated in Figure 5 below; where an individual's career path is the precise combination of the forces they undergo in the roles & positions she performs in over her entire career.

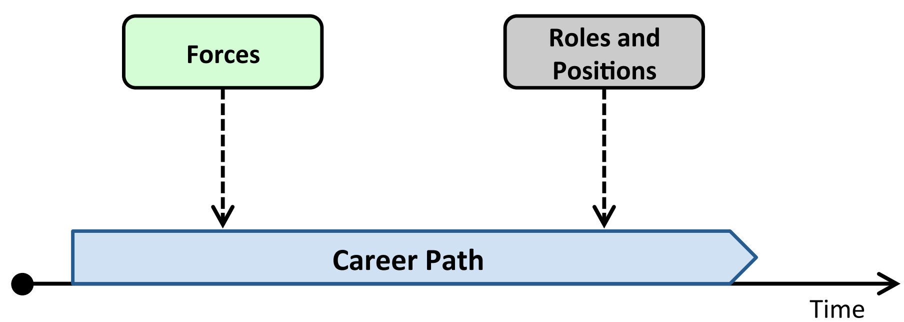


Figure 5. Career Path: A Dynamic View of *Atlas*

Leading up to the publication of *Atlas 0.5*, the Helix team defined methods to depict and analyze the career paths of systems engineers and used those methods to analyze the systems engineers in its interview sample, and how those systems engineers are shaped by the impact of forces and roles & positions over time.

6.3 INCREMENTAL *ATLAS* DEVELOPMENT

Atlas is being developed incrementally:

- **Atlas 0.25:** The first draft of *Atlas* based on work done in 2014 was published as *Atlas 0.25* in November 2014. It included key elements that explain the effectiveness of systems engineers, and a preliminary explanation of their relationships. The structure and variables of the proficiency model was also included, along with some initial analysis of career paths.
- **Atlas 0.5:** Based on subsequent work done in 2015, *Atlas 0.5* is now being published in this report. It reflects further understanding of the elements of *Atlas* and their inter-relationships. Significant new work done in the area of career paths is included. It also reports initial efforts to use *Atlas* to assess the level of proficiency of systems engineers. *Atlas 0.5* is mature enough for an individual or an organization to use and gain valuable insights with some guidance from the Helix team.
- **Atlas 1.0:** Planned for release towards the end of 2016, *Atlas 1.0* will include a more complete description of the elements of *Atlas* and their inter-relationships. *Atlas 1.0* is expected to be mature enough for independent deployment and assessment by individuals and organizations with little or no guidance from the Helix team. In addition, *Atlas 1.0* is expected to be validated using data from outside the DoD, and may therefore be applicable to systems engineers in a variety of domains. An intermediate version of *Atlas* may be published earlier in 2016.

6.4 *ATLAS* DEPLOYMENT

As described in the preceding sub-section, the intent is to develop *Atlas* so that it can be independently deployed by individuals and organizations. Since *Atlas 0.25* was mature enough for trial, it was used in some organizations during 2015 to assess the proficiency levels and understand the career paths of individual systems engineers. Feedback and observations from these trials have already influenced the development of *Atlas 0.5* published in this report. A glimpse into potential benefits of *Atlas* deployment, based on trials conducted in 2015, are included in Section 18 of this report.

PART 2

ELEMENTS OF *ATLAS*:

THE THEORY OF EFFECTIVE SYSTEMS ENGINEERS

Part 2 discusses the various elements of *Atlas*. Section 7 presents underlying definitions and classifications that are fundamental to *Atlas* and to all subsequent discussions across this report. Sections 8 through 12 elaborate on the different elements of *Atlas*, as indicated in Figure 6 below.

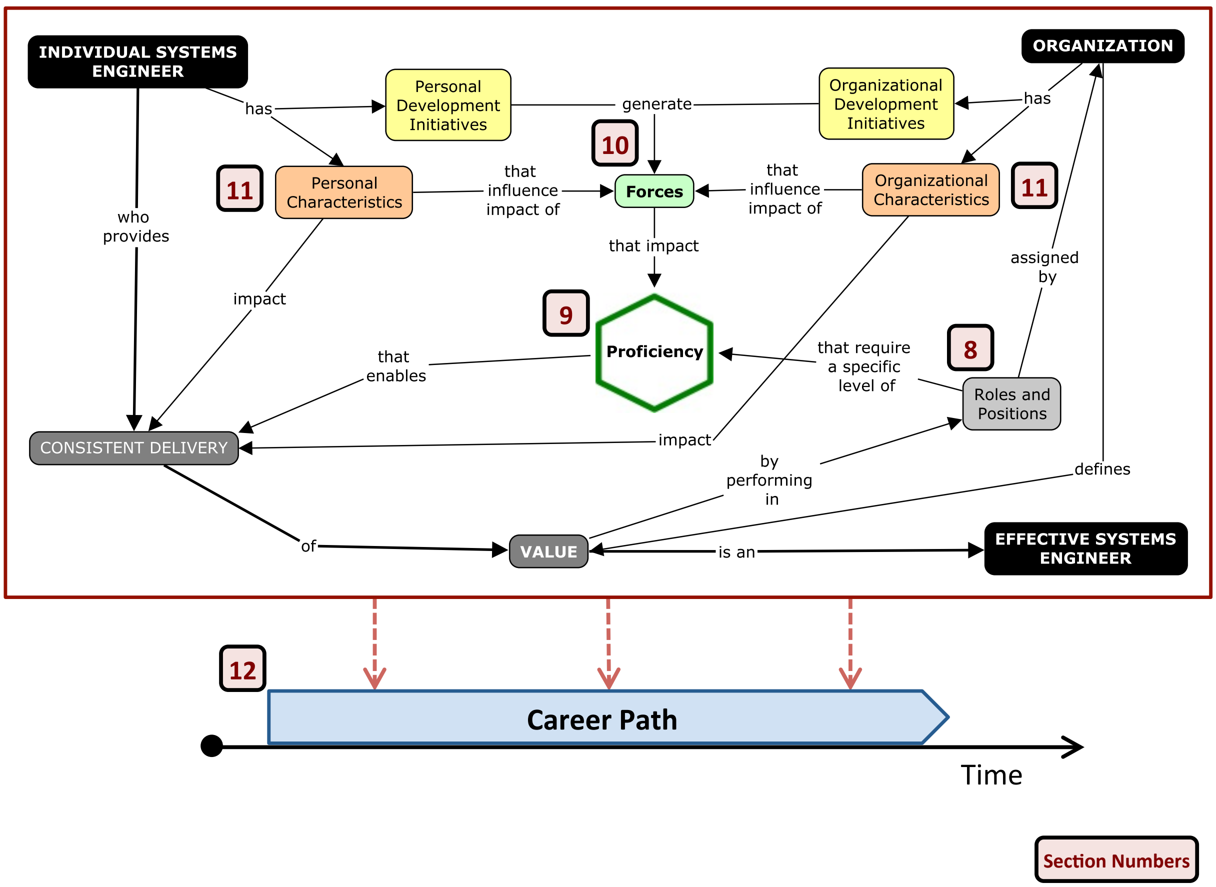


Figure 6. Elements of *Atlas*

Atlas is the product of the research and analysis performed by Helix. Since a grounded theory based approach was followed, *Atlas* is the aggregation of the themes and constructs identified from the data. Insights from Helix data with respect to *Atlas* are elaborated in Part 3; Part 2 is focused primarily on describing *Atlas*.

7 Underlying Definitions and Classifications

Consistency in the definition and understanding of terminology and concepts is essential for any deliberation. This section presents the definitions and classifications that are relevant to *Atlas*. Some have been obtained from available literature, while others have been created specifically for *Atlas*.

7.1 *Atlas* Definitions

- **Systems Engineer**

  *A **Systems Engineer** is an individual who performs systems engineering activities and is recognized (either formally or informally) by his or her organization for her ability to perform these activities.*

  This definition of a systems engineer does *not* refer to the title that someone may hold in her organization. Someone may never hold the title 'Systems Engineer', but could be considered to be one based on the activities she performs. Similarly, someone may hold the title 'Systems Engineer', but her activities may not be considered to be systems engineering activities.

- **Effective Systems Engineer**

  *An **Effective Systems Engineer** is someone who consistently delivers value by performing systems engineering activities in positions assigned by the organization.*

  This definition is fundamental to *Atlas* since the focus of Helix research is the effectiveness of systems engineers. Though 'effectiveness' is a subjective term, this definition ties it to 'value' that can be defined and even measured – qualitatively, if not quantitatively.

- **Chief Systems Engineer (CSE)**

  *A **Chief Systems Engineer (CSE)** is one who has formal responsibility to oversee and shepherd the technical correctness and to maintain a consistent vision for a system, often coordinating with many other systems engineers who have smaller scopes of responsibility.*

  The Chief Systems Engineer (CSE) position is one of the most senior technical positions that system engineers can achieve while staying in a technical track (as opposed to a management track). Though the title 'Chief Systems Engineer' is not used in all organizations, the concept of a CSE position (or equivalent) is common, especially in industry. There is no consistent description of a CSE's (or equivalent's) formal authority, but overall responsibility for a system is often split in some way between the CSE and the project or program manager (PM).

- **Position**

  *A **Position** held by an individual is equivalent to a 'title', where the organization defines what roles and responsibilities it entails.*

  This definition of a position is usually specific to an organization and does not translate across organizations.

- **Role**

  *A **Role** performed by an individual consists of a specific set of related activities.*

  Typically, an individual performs multiple roles in any given position. In the context of *Atlas*, the roles of interest are systems engineering roles.

- **Career Path**

  *An individual's **Career Path** is the precise combination (in terms of characteristics, timing, and order) of experiences, mentoring, and education and training that they undergo during their entire career.*

  This definition, created for *Atlas*, is different from how career paths are typically defined in the human resources (HR) community. HR definitions tend to be focused on rigid hierarchy that may be useful for HR classification and management of positions within an organization. However, they provide little insight into the growth and development of individuals throughout their career, particularly across organizations.

- **Proficiency**

  *The **Proficiency** of an individual is the quality or state of knowledge, skills, abilities, behaviors, and cognition.*

  In *Atlas*, the term 'proficiency' is used broadly to include everything that an individual needs to be good at in order to be an effective systems engineer. This distinguishes *Atlas* from competency models that tend to focus primarily on the discipline of systems engineering.

7.2 *ATLAS* CLASSIFICATIONS

- **Seniority of a Systems Engineer**

  As systems engineers traverse the path of their careers from the point of entry into the workforce (or recruitment) to the point or exit from the workforce (or retirement), there is a continual maturation that is reflected in the breadth and depth of their proficiencies; the types of roles & positions they play; and the value that they provide or that is expected from them. Grouping systems engineers under some levels of 'seniority' that reflect the levels of maturation enables patterns to be identified across systems engineers, and insights to be drawn from them.

  Helix has identified three levels of seniority in systems engineers: junior, mid-level, and senior.

Traditionally, ‘number of years of work experience’ has been used as a preliminary criterion for distinguishing between these levels of seniority, but it fails to capture the nuances of differentiation within systems engineers. Hence, it is not included in Table 2 that states various criteria used to distinguish between junior, mid-level, and senior systems engineers. These criteria are meant to be indicative and not rigid; there are always examples of specific individuals whose seniority is not consistent with these criteria.

Table 2. Criteria for Distinguishing the Seniority of Systems Engineers

	Junior	Mid-level	Senior
1.	Not more than 1 formal leadership position	At least 2 formal leadership positions	More than 2 formal leadership positions
2.	Experiences primarily in components	Experiences in components and subsystems, and perhaps in systems	Experiences in components, subsystems, systems, and perhaps in systems of systems
3.	Experiences in at least 2 aspects of the systems lifecycle	Experiences in at least 3 aspects of the systems lifecycle	Experiences in at least 4 aspects of the systems lifecycle

With respect to Table 2:

1. Experience is considered to be ‘relevant’ if it directly supports the growth of systems engineering proficiencies.
2. A leadership position is ‘formal’ if it is officially defined and recognized by the organization. This does not mean that the individual necessarily has organizational authority over the individuals she is leading. Likewise, there is no defined minimal team size. Typically, early leadership positions are over small teams (less than five people) and as the individual matures, the size of the teams increases.
3. The hierarchy of system levels (components -> subsystems -> systems -> system of systems) is based on definitions from the *Guide to the Systems Engineering Body of Knowledge* (BKCASE Editorial Board 2015) and reflects system complexity and completeness, where ‘parts’ at any level are combined to form the ‘whole’ at the next level.
4. The various aspects of the systems lifecycle are based on definitions from the *Guide to the Systems Engineering Body of Knowledge* (BKCASE Editorial Board 2015) and are elaborated in Section 9.5.
5. Formal education, titles, and roles are *not* considered to be distinguishing criteria, since they cannot be used to consistently draw any distinctions between levels of seniority of systems engineers. However, as a baseline, systems engineers typically have an undergraduate degree in a STEM (science, technology, engineering, and mathematics) field.

8 ROLES AND POSITIONS

An individual systems engineer fills a position (or holds a title) in an organization, and there are many roles that the systems engineer is expected to perform in that position. *Atlas* identifies 16 systems engineering roles; typically, a systems engineer performs a combination of these roles while holding a single position. Starting with the 'twelve systems engineering roles' identified by Sheard (1996), Helix added five more to reflect additional roles reflecting Helix data collected during interviews about the activities systems engineers perform in organizations today. The role of 'Classified Ad' identified by Sheard is not included in *Atlas,* since it was used to include positions often posted in job listings (such as 'Microsoft Systems Engineer'), and was not a role that systems engineers, as defined by *Atlas*, actually performed. Table 3 below, describes each of the 16 roles identified by *Atlas*.

Table 3. Roles of a Systems Engineer

#	Role (Abbreviation)	Description
1.	**Requirements Owner** +	Individual who is responsible for translating customer requirements to system or sub-system requirements; or for developing the functional architecture.
2.	**System Designer (SD)** +	Individual who is responsible for owning or architecting the system; common titles may includes chief systems engineer or system architect.
3.	**System Analyst (SA)** +	Individual who provides modeling or analysis support to system development activities, and helps to ensure that the system as designed meets he specification.
4.	**V&V Engineer (VV)** +	Individual who plans and conducts verification and validation activities such as testing, demonstration, and simulation.
5.	**Logistics/ Operations Engineer (LO)** +	Individual who performs the 'back end' of the SE lifecycle, who may operate the system, provide support during operation, provide guidance on maintenance, or help with disposal.
6.	**Glue (GL)** +	Individual who is responsible for a holistic perspective of the system; this may be the 'technical conscience' or 'seeker of issues that fall *in the cracks*' – particularly, someone who is concerned with interfaces.
7.	**Customer Interface (CI)** +	Individual who is responsible for coordinating with the customer, particularly for ensuring that the customer understands technical detail and that a customer's desires are, in turn, communicated to the technical team.
8.	**Technical Manager (TM)** +	Individual who is responsible for controlling cost, schedule, and resources for the technical aspects of a system; often someone who works in coordination with an overall project or program manager.
9.	**Information Manager (IM)** +	Individual who is responsible for the flow of information in a system development activity; specific activities may include configuration management, data management, or metrics.
10.	**Process Engineer (PE)** +	Individual who is responsible for the systems engineering process as a whole; who also likely has direct ties into the business.

#	Role (Abbreviation)	Description
11.	Coordinator (CO) +	Individual who is responsible for coordination amongst a broad set of individuals or groups who help to resolve systems related issues.
12.	Systems Engineering Evangelist (EV) +++	Individual who promotes the value of systems engineering to individuals outside of the SE community - to project managers, other engineers, or management.
13.	Detailed Designer (DD) ++	Individual who provides technical designs that match the system architecture; an individual contributor in any engineering discipline who provides part of the design for the overall system.
14.	Organizational/ Functional Manager (MG) ++	Individual who is responsible for the personnel management of systems engineers or other technical personnel in a business – not a project or program – setting.
15.	Instructor/ Teacher (IN) +++	Individual who is responsible for providing or overseeing instruction of SE discipline, practices, processes, etc.
16.	Program/Project Manager (PM) ++	Individual who performs program or project management activities; who is not directly responsible for the technical content of a program, but works closely with technical experts and other systems engineers.

+ Roles identified by Sheard (1996) [Roles 1 – 11 above]

++ Roles identified by Helix [Roles 13, 14, and 16 above]

+++ Roles recommended in Sheard (2000) and adopted by Helix based on the data available [Roles 12 and 15 above]

9 Proficiency of Systems Engineers

The proficiency model in *Atlas*, captures the knowledge, skills, abilities, behaviors, patterns of thinking, and abilities that are critical to the effectiveness of systems engineers.

9.1 Generic Proficiency Framework

The various elements of proficiency gathered are aggregated into a 3-level hierarchy, as illustrated in Figure 7 below:

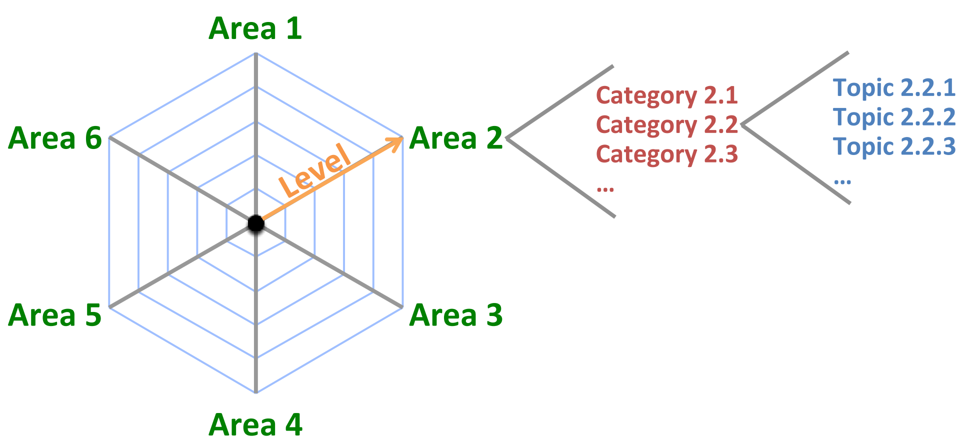


Figure 7. *Atlas* Proficiency Framework

- **Proficiency** is the quality or state of knowledge, skills, abilities, behaviors, and cognition.
- Proficiency **Areas** are groupings of related knowledge, skills, abilities, behaviors, and/or cognition.
- Each Proficiency Area is comprised of **Categories**, which are specific types of knowledge, skills, abilities, behaviors, and cognition with shared characteristics.
- *Some* categories are further refined into **Topics**, which are the most discrete areas of proficiency included in *Atlas*.
- For each proficiency area, there are **Levels**, which describe the extent to which an individual has attained certain knowledge, has the ability to perform a certain skill, or has demonstrated relevant abilities, behaviors, or cognition. Loosely, a scale of 1 to 10 is used to indicate the level of proficiency at the area level, where 10 indicates the highest possible proficiencyl. These scales will be further developed in *Atlas 1.0*.

The *Atlas* proficiency framework along with the proficiency levels, enable a proficiency profile to be created for an individual at any point in time, as illustrated in Figure 8. Currently, proficiency levels are being considered only at the Area level.

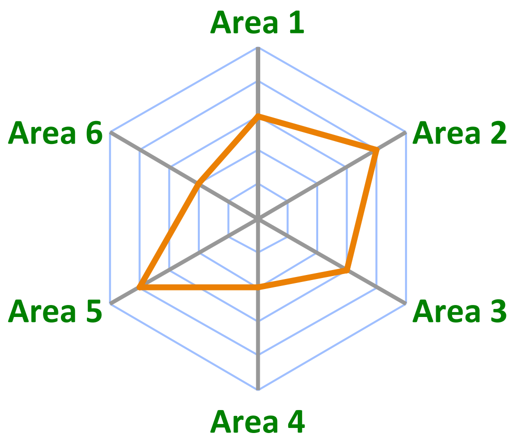


Figure 8. Sample Proficiency Profile

9.2 *ATLAS* PROFICIENCY MODEL

The *Atlas* proficiency model consists of six proficiency areas based on the Helix interview data, as shown in Figure 9 below.

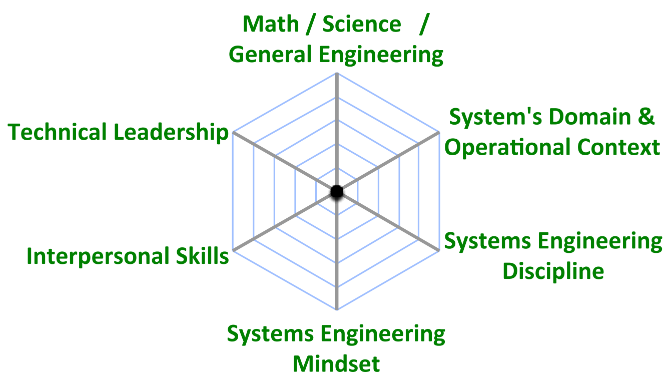


Figure 9. Proficiency Areas for Systems Engineers

1. ***Math/Science/General Engineering:*** Foundational concepts from mathematics, physical sciences, and general engineering;
2. ***System's Domain & Operational Context***: Relevant domains, disciplines, and technologies for a given system and its operation;
3. ***Systems Engineering Discipline***: Foundation of systems science and systems engineering knowledge;
4. ***Systems Engineering Mindset***: Skills, behaviors, and cognition associated with being a systems engineer;
5. ***Interpersonal Skills***: Skills and behaviors associated with the ability to work effectively in a team environment and to coordinate across the problem domain and solution domain; and

6. ***Technical Leadership***: Skills and behaviors associated with the ability to guide a diverse team of experts toward a specific technical goal.

Proficiency areas 1 to 3 may be considered to be the more 'hard' or technically based skills, while proficiency areas 4 to 6 may broadly be considered to be 'soft skills'. Development and evaluation of soft skills is addressed by the disciplines of psychology, social sciences, and management sciences. The six proficiency areas in *Atlas* are further divided into categories and, in some cases, into topics, as shown in Table 4. Each of the proficiency areas is elaborated in the subsequent sections.

Table 4. Atlas Proficiency Areas, Categories, and Topics

Area	Category	Topic
1. Math / Science / General Engineering	1.1. Natural Science Foundations	
	1.2. Engineering Fundamentals	
	1.3. Probability & Statistics	
	1.4. Calculus & Analytical Geometry	
	1.5. Computing Fundamentals	
2. Systems' Domain & Operational Context	2.1. Relevant Domains	
	2.2. Relevant Technologies & Systems	
	2.3. Relevant Disciplines	
	2.4. Familiarity with System's Concept of Operations (ConOps)	
3. Systems Engineering Discipline	3.1. Lifecycle	3.1.1 Lifecycle Models; 3.1.2 Concept Definition; 3.1.3 System Definition; 3.1.4 System Realization; 3.1.5 System Deployment & Use; 3.1.6 Product & Service Life Management
	3.2. Systems Engineering Management	3.2.1 Planning; Risk Management; 3.2.2 Configuration Management; 3.2.3 Assessment & Control; 3.2.4 Quality Management
	3.3. SE Methods, Processes, & Tools	3.3.1 Balance & Optimization; 3.3.2 Modeling & Optimization; 3.3.3 Development Process; 3.3.4 Systems Engineering Tools
	3.4. System Complexity	
4. Systems Engineering Mindset	4.1. Big-Picture Thinking	
	4.2. Paradoxical Mindset	4.2.1 Big-Picture Thinking and Attention to Detail; 4.2.1 Strategic and Tactical; 4.2.1 Analytic and Synthetic; 4.2.1 Courageous and Humble; 4.2.1 Methodical and Creative
	4.3. Flexible Comfort Zone	
	4.4. Abstraction	
	4.5. Foresight & Vision	

Area	Category	Topic
5. Interpersonal Skills	5.1. Communication	5.1.1 Audience; 5.1.2 Content; 5.1.3 Mode
	5.2. Listening & Comprehension	
	5.3. Working in a Team	
	5.4. Influence, Persuasion & Negotiation	
	5.5. Building a Social Network	
6. Technical Leadership	6.1. Building & Orchestrating a Diverse Team	
	6.2. Balanced Decision Making & Rational Risk Taking	
	6.3. Managing Stakeholders and their Needs	
	6.4. Conflict Resolution & Barrier Breaking	
	6.5. Business & Project Management Skills	

9.3 Area 1: Math/Science/General Engineering

A good understanding of math, science, and general engineering is a critical foundation for effective systems engineers; but this understanding is largely 'assumed' in a systems engineer when joining the workforce since proficiency in this area is not utilized directly or in isolation. However, it is upon this foundation that further understanding of the categories under Proficiency Area 2: *Systems' Domain & Operational Context* is built.

The *Graduate Reference Curriculum for Systems Engineering (GRCSE®)* defines the types of prerequisite knowledge individuals should have before entering a master's program in systems engineering (Pyster et al. 2015). Since limited insight was obtained from Helix data collection and analysis for this proficiency area, GRCSE is used to identify and define the categories in this area:

1.1. **Natural Science Foundations:** Basic concepts and principles of one of the natural science disciplines (e.g., physics, biology, chemistry, etc.); includes laboratory work that involves experimental techniques, the application of the scientific method, and comprehension of appropriate methods for data quality assurance and analysis.

1.2. **Engineering Fundamentals:** The nature of engineering, branches of engineering, the design process, analysis and modeling, the role of empirical and statistical techniques, problem solving strategies, and the value of standards; some level of practical experience is expected, whether through capstones, internships, or course projects. Practical experience should include the application of engineering fundamentals in a specific domain context.

1.3. **Probability and Statistics:** Basic probability theory, random variables and probability distributions, estimation theory, hypothesis testing, regression analysis, and analysis of variance.

1.4. **Calculus and Analytical Geometry:** Theory and application of differential and integral calculus methods and operations; study of techniques for describing, representing, and analyzing geometric objects (coordinate systems, algebraic models, graphing).

1.5. **Computing Fundamentals**: Overview of computer organization (computer architecture, operating systems, and programming languages), algorithms, and data structures; software engineering fundamentals (lifecycle models, quality, cost, and schedule issues); and development of a software unit (design, coding, and testing).

9.4 AREA 2: SYSTEM'S DOMAIN & OPERATIONAL CONTEXT

The second proficiency area is *System's Domain & Operational Context*, which contains the relevant domains, disciplines, technologies for a given system, and the operation of that system. This proficiency area is strongly tied to the system(s) on which an individual systems engineer is working. If that individual transitions to a new system, the proficiency level may change depending on familiarity with the new relevant domains, technologies, and disciplines. The categories for this proficiency area are defined below:

- **2.1. Relevant Domains**: *Domain* refers to the overarching area of application of the system; this includes things such as space, aerospace, marine, communication, finance, etc. Proficiency in related domains outside the primary one may enable an individual to be more effective in the primary domain. For example, experience in space systems may enable a systems engineer to work in aerospace systems more readily than an engineer who is proficient primarily in communication systems.
- **2.2. Relevant Technologies & Systems**: Within the context of a system, there are specific technologies that are relevant. Similarly, there are other enabling or support systems that are also relevant. For example, on a marine system, there may be technologies such are gas turbine, radar, and sonar systems; and each technology has its own terminology, challenges, etc. Similarly, if a combat ship were the system, relevant systems could be submarines and aircraft carriers.
- **2.3. Relevant Disciplines**: Disciplines are fundamental areas of education or expertise that are foundational to a system. For example, for a communications system, electrical engineering will be an important discipline to understand, while civil engineering will be less relevant. It is likely that there may be more than one relevant discipline.
- **2.4. Familiarity with System's Concept of Operations (ConOps)**: A system's concept of operations (ConOps) of how systems in the domain are used and deliver value, especially those systems on which the individual personally works.

9.5 AREA 3: SYSTEMS ENGINEERING DISCIPLINE

The third proficiency area is *Systems Engineering Discipline*. The categories below were developed based on data from Helix interviews about critical systems engineering knowledge and skills. The names of the categories come from the *Guide to the Systems Engineering Body of Knowledge (SEBoK)* (BKCASE Editorial Board 2015). Some of the categories are further expanded into topics.

- **3.1. Lifecycle:** *The organized collection of activities, relationships and contracts that apply to a system-of-interest during its life* (Pyster 2009). This is a roll up of knowledge about lifecycles and proficiency in specific aspects of the lifecycle. Topics 3.1.2 – 3.1.6 below, represent generic lifecycle phases in system development:
  - **3.1.1. Lifecycle Models**: *A framework of processes and activities concerned with the lifecycle that may be organized into stages, which also acts as a common reference for communication and understanding* (ISO/IEC/IEEE 15288). Lifecycle Models include Vee model; iterative models such as the spiral development model; formal acquisition models

(e.g., as defined in DoD 5000.2 2013); or less formal acquisition models (e.g., quick reaction capability or internal research and development (IR&D) models).

3.1.2. Concept Definition: *A set of core technical activities of systems engineering in which the problem space and the needs of the stakeholders are closely examined* (BKCASE Editorial Board 2015). This consists of analysis of the problem space, business or mission analysis, and the definition of stakeholder needs for required services.

3.1.3. System Definition: *A set of core technical activities of systems engineering, including the activities that are completed primarily in the front-end portion of the system design.* (BKCASE Editorial Board 2015) This consists of the definition of system requirements, the design of one or more logical and physical architectures, and analysis and selection between possible solution options.

3.1.4. System Realization: *The activities required to build a system, integrate disparate system elements, and ensure that a system both meets the needs of stakeholders and aligns with the requirements identified in the system definition stage* (BKCASE Editorial Board 2015). This includes implementation as well as integration, verification, and validation (IV&V).

3.1.5. System Deployment and Use: *A set of core technical activities of systems engineering to ensure that the developed system is operationally acceptable and that the responsibility for the effective, efficient, and safe operations of the system is transferred to the owner* (BKCASE Editorial Board 2015). Considerations for deployment and use must be included throughout the system lifecycle. Activities within this phase include deployment, operation, maintenance, and logistics.

3.1.6. Product and Service Life Management: Deals with the overall lifecycle planning and support of a system (BKCASE Editorial Board 2015). The life of a product or service often spans a considerably longer period of time than the time required to design and develop the system. This stage includes service life extension, updates, upgrades, and modernization, and disposal and retirement.

3.2. Systems Engineering Management: *Managing the resources and assets allocated to perform systems engineering, often in the context of a project or a service, but sometimes in the context of a less well-defined activity. Systems engineering management is distinguished from general project management by its focus on the technical or engineering aspects of a project* (BKCASE Editorial Board 2015). The topics contained in the *Systems Engineering Management* category are defined below:

3.2.1. Planning: Planning involves developing and integrating technical plans to achieve the technical project objectives within the resource constraints and risk thresholds. This involves the success-critical stakeholders to ensure that necessary tasks are defined with the right timing in the lifecycle in order to manage acceptable risks levels, meet schedules, and avoid costly omissions (BKCASE Editorial Board 2015).

3.2.2. Risk Management: Organized, analytic process to identify what might cause harm or loss (identify risks); to assess and quantify the identified risks; and to develop and, if needed, implement an appropriate approach to prevent or handle causes of risk that could result in significant harm or loss (ISO/IEC/IEEE 24765:2010 – SEVocab).

3.2.3. Configuration Management: A discipline applying technical and administrative direction and surveillance to: identify and document the functional and physical characteristics of a configuration item, control changes to those characteristics, record and report change processing and implementation status, and verify compliance with specified requirements (ISO/IEC/IEEE 24765:2010 – SEVocab).

3.2.4. Assessment and Control: This process involves determining and initiating the appropriate handling strategies and actions for findings and/or discrepancies that are uncovered in the enterprise, infrastructure, or lifecycle activities associated with the project (BKCASE Editorial Board 2015).

3.2.5. Quality Management: Whether a systems engineer delivers a product, a service, or an enterprise, the deliverable should meet the needs of the customer and be fit for use. Such a deliverable is said to be of high quality. The process to assure high quality is called quality management (BKCASE Editorial Board 2015).

3.3. SE Methods, Processes, and Tools: *A systems engineering method is set of activities, methods, practices, and transformations that people use to develop and maintain systems and associated products* (SEI 2007). Processes generally refer to the specific guidelines an organization develops for implementing systems engineering methods and tools refer to software programs that are designed to support systems engineering activities. The topics contained in the *SE Methods, Processes, and Tools* category are outlined below:

3.3.1. Balance and Optimization: Specialty engineers are often focused on the details and optimization of their specific components of the system, but that optimization of individual components often leads to a less-than-optimal system solution. Systems engineers, therefore, have to be able to balance the desire for component optimization with the optimization for the system overall, which often requires sub-optimization for one or more components.

3.3.2. Modeling and Simulation: *A model is a simplified representation of a system at some particular point in time or space intended to promote understanding of the real system. A simulation is the manipulation of a model in such a way that it operates on time or space to compress it, thus enabling one to perceive the interactions that would not otherwise be apparent because of their separation in time or space* (Bellinger 2004). This topic represents and individual's ability to understand and perform modeling and simulation; this understanding is more fundamental than the ability to use software tools that support modeling and simulation.

3.3.3. Development Processes: Each organization has its own processes that govern the development of systems. It is important for systems engineers to understand generic systems engineering processes, but also the specific processes being used for development within the organization or domain.

3.3.4. Systems Engineering Tools: Systems engineers need to be able to utilize tools to support overall system development and to perform the systems engineering development process. Tools may include requirements management and other tools that assist with project life management (PLM).

3.4. System Complexity: *The degree to which a system's design or code is difficult to understand because of numerous components or relationships among components* (ISO/IEC 2009). In this context, the proficiency is the level of complexity an individual can handle. This may include things such as their ability to work on components, subsystem, systems, or systems of systems as well as the ability to work on products, platforms, services, or enterprises. Note that others have equated a system's complexity with the degree to which that system's behavior cannot be predicted. There are numerous measures of systems complexity in the literature, and at this point in time, the Helix team does not have a generic measure of complexity.

9.6 Area 4: Systems Engineering Mindset

The fourth proficiency area is *Systems Engineering Mindset*, which is primarily focused on patterns of thinking, perceiving, and approaching a task that are particularly relevant to systems engineers. The categories included in this area are:

4.1. **Big-Picture Thinking**: Also referred to as 'systems thinking' and 'holistic thinking', this includes the ability to step back and take a broader view of the problem at hand; this is an important and essential characteristic of systems engineers. 'Big-picture' could refer to a broader perspective along many different dimensions: the system as a whole including interfaces and integration, and not limited to any sub-system or component; the system while in operation, and its interactions with other systems and the operating environment; the entire lifecycle of the system, and not limited to the current stage of the system; the development program in the context of the organization and all its other development programs; the end goal or solution to the problem at hand; the perspectives of different stakeholders; and the technical as well as business perspectives. A systems engineer is usually *the* person to bring this broader perspective, while specialty engineers and subject matter experts often tend to be narrowly focused on their area of interest. Systems engineers are not only called to provide this big-picture perspective themselves, but to also enable others to see this bigger picture.

4.2. **Paradoxical Mindset**: *The ability to hold and balance seemingly opposed views, and being able to move from one perspective to another appropriately*. Typically, an engineer may hold one view or the other, but rarely *both*. By having this paradoxical mindset, a systems engineer contributes value that is not usually expected from others. The opposing-concept pairs are:

4.2.1. **Big-Picture Thinking *and* Attention to Detail:** Big-picture thinking provides the broader higher-level perspective; at the same time, a systems engineer is also required to pay attention to the details of how things work and how they come together in a system.

4.2.2. **Strategic *and* Tactical:** Systems engineers need to be strategic, focused on the end result of 'vision' for the system, but also need to handle the tactical day-to-day activities and decisions required to reach that vision. They must also be able to appreciate "how what is done today is going to affect things downstream". A related concept pair is the ability to envision long-term issues but at the same time, have the desire for closure with the current situation in order to move on.

4.2.3. **Analytic *and* Synthetic:** A big-picture perspective may be associated with the ability to be synthetic, and to be able to bring together and integrate different pieces of a puzzle together. However, a systems engineer also needs to be analytic and to be able to break down the big picture into smaller pieces on which others can focus and work. To do this effectively, a systems engineer needs to be able to operate at multiple levels (e.g., component, sub-system, system, system-of-systems) and multiple dimensions (e.g., various technical disciplines and stakeholder perspectives).

4.2.4. **Courageous *and* Humble:** Systems engineers need to be courageous as leaders; the proficiency area *Technical Leadership* discusses many elements of this. At the same time, they also need to be humble enough to recognize that there are others who are experts in their individual areas of specialization. They are confident in their abilities to make a tough judgment call with a 'lack of pride', but also willing to recognize and accept their mistakes.

4.2.5. **Methodical *and* Creative:** Systems engineers need to be disciplined, organized, diligent, methodical, and process-oriented in their approach; they need to stay focused on the end-result and the path towards that. However, they also need to be creative in thinking through the problems at hand and arriving at solutions, without compromising the disciplined approach. There is a need for systems engineers to be flexible and adaptable, in order to effectively respond to change and unexpected disruptions.

4.3. **Flexible Comfort Zone**: *The overall ability to deal with ambiguity and uncertainty, this involves the abilities to be open-minded, understand multiple disciplines, deal with challenges, and ability to take rational risks*. By definition, experts possess proficiency in a specific area, which is their 'comfort zone'; and they typically do not prefer going outside that circle or comfort zone. Such experts provide value to the organization by contributing their expertise in those focused areas. However, systems engineers tend to show an ability to broaden their comfort zones, and go beyond their current boundaries and they are also comfortable doing this.

4.4. **Abstraction**: *The ability to filter out and understand the critical bits of information at the right level and to make relevant inferences*. And even with that filtered information, systems engineers need to know when to use or not use pieces of information. Such abstraction also enables systems engineers to connect and extract meaning from different streams of information; for example, to tie together information that subject matter experts of two different disciplines are providing.

4.5. **Foresight and Vision**: *The ability to foresee the remaining lifecycle of the system, the impact of current decisions, and to mentally simulate possible scenarios*. Every decision or change is likely to have an impact beyond the current confines of time or space. Particularly in early stages of a system lifecycle, and in the development of a new or unfamiliar system, foresight is a key value that systems engineers provide.

9.7 AREA 5: INTERPERSONAL SKILLS

The fifth proficiency area is *Interpersonal Skills*. Almost by definition, systems engineers do not just work by themselves at their desks all day – they interact with people. Irrespective of any formal leadership roles they may or may not play, a systems engineer is expected to be proficient in a number of interpersonal skills. While specialty engineers may be responsible for developing specific aspects of the system, systems engineers are responsible for coordinating across all of these engineers. Hence, interpersonal skills are more critical to systems engineers than they are to specialty engineers. The specific categories contained within this proficiency area are listed below:

5.1. **Communication:** Communication is critical for systems engineers since they interact with a variety of people, and is a broad category covering a wide variety of related skills and abilities. Often they are an important link between individuals and groups, both internal and external to the organization – most importantly, the customers and end-users of the system being developed. Systems engineers need the ability to clearly express their thoughts and perspectives to establish a shared common understanding.

5.1.1. Audience: Systems engineers need to communicate with a variety of direct and indirect audiences: customers; subject matter experts; program managers; vice presidents; directors; specialty engineers; problem owners; technical teams; contractors; decision makers; system testers; and others working on the project.

5.1.2. Content: The variety of content that systems engineers need to communicate can be broadly divided into three types, based on the audience they are communicating with:

1. **Technical**: Communications with disciplinary and specialty engineers and subject matter experts involve high technical content. But communications of technical issues to managers, end-users, and others who may not be interested in or who may be confused by all the technical detail, involves adequate abstraction of the technical content.

2. **Managerial**: Systems engineers often provide project status to managers and supervisors and cost-schedule constraints and expectations to technical personnel.

3. **Social**: Systems engineers need to maintain an amicable environment within a team and to interact with others in a courteous manner. Such interactions involve communications that are neither technical nor managerial in nature.

5.1.3. Mode: Communicating the intended content to the target audience is done through a number of different modes:

1. **Oral:** This takes various forms, depending on the audience and context. It could be one-on-one, or as part of a team, in person, or remotely.

2. **Presentation**: A special form of communications is the ability to stand in front of an audience and to deliver a presentation using appropriate aids. Further, during presentations, systems engineers tend to represent others who may not be in the room: they present customer needs and requirements to others in the absence of customers, and they present design decisions and system related issues to customers in the absence of designers.

3. **Writing and Documentation:** Written communication skills are equally critical for systems engineers; the scale, audience, and objective of the written artifact also matter. It could range from a short email to communicate status, to a detailed test plan, to internal documentation supporting a project decision, to a comprehensive design document being submitted for a Critical Design Review.

5.2. Listening and Comprehension: The ability to listen to others' points of views and perspectives, and to comprehend and internalize the message accurately. For systems engineers, listening begins with the customer to understand their real needs and ensure that these needs get translated into requirements. In a team environment, systems engineers need to listen to the views and perspectives being offered: from designers, subject matter experts, and others.

5.3. Working in a Team: Systems engineers tend to be part of many teams during the lifecycle of the system; further, systems engineering by itself is typically not performed by an individual, but rather by a team. Hence, team dynamics and synergy are key to the functioning of a systems engineer.

5.4. Influence, Persuasion, and Negotiation: It is critical for every systems engineer, not just those in formal leadership positions, to have the skills needed to make a point and to successfully obtain buy-in. In many situations, systems engineers bring in a perspective that is different from what others may bring in: a focus on the overall system, and on customer's needs. In such situations, it requires influence, persuasion, and negotiating skills for systems engineers to enable others to see the bigger picture on which they need to focus.

5.5. **Building a Social Network:** A systems engineer needs to be a 'people person', and build a social network of professional acquaintances. Such a network becomes a valuable resource for systems engineers to tap into, because they are not expected to know answers to all problems, but rather be able to find someone who has the expertise and ability to solve the problem.

9.8 Area 6: Technical Leadership

The sixth and final *Atlas* proficiency area is *Technical Leadership*. It is common and natural for systems engineers to play leadership roles at many levels within an organization. The specific categories contained within *Technical Leadership* are listed below:

6.1. **Building and Orchestrating a Diverse Team**: *The ability to identify, build, and effectively guide or coach a team comprising individuals with diverse expertise, perspectives, and personalities*. While organizational titles may vary, it is most often a systems engineer who is the leader of the team that is charged with delivering the system. The systems engineer needs to fully know each of the team members: their strengths, weaknesses, capacities, capabilities, limitations, personalities, expertise, and working styles. The systems engineer plays the roles of coach, guide, and teacher to develop the team's capabilities and to orchestrate it to perform the required tasks. Individual leadership styles could vary, but the overall objective of is to empower the team, to instill confidence, and to help them to deliver the solution and to be successful. Another key aspect of handling a team is the ability to delegate – the leader needs to build enough trust in the team to be able to delegate with confidence.

6.2. **Balanced Decision Making and Rational Risk Taking:** Solving a problem requires a systems engineer to take a number of balanced decisions considering a variety of factors, constraints, perspectives, and objectives; as well as the implications of these decisions and their scope of impact. An additional challenge is that most often, all the required information may not be readily available. The ability to make such decisions also requires the systems engineer to be comfortable in dealing with ambiguity and uncertainty and to be able to take rational, calculated risks.

6.3. **Managing Stakeholders and their Needs:** This includes the ability to manage all the internal and external stakeholders, and to keep the team focused on their needs, especially those of the end user or customer. The systems engineer is uniquely positioned to interact with many stakeholders of the system – both external and internal to the organization. Being this "touch point" person, the systems engineer needs to deal with multiple personalities, behaviors, organizations, and cultures.

6.4. **Conflict Resolution and Barrier Breaking**: Conflicts are bound to rise in a variety of scenarios – within the team; within the organization – between the technical side and business side of the organization; as well as with outside the organization. As a leader, it is upon the systems engineer to resolve these conflicts while keeping the system goals in mind. In some cases, conflicts arise due to the existence of barriers, which may be related to the organizational culture, processes, team personalities, or other situations that could prevent an individual or team from getting their work done. The systems engineer needs the ability to break these barriers.

6.5. Business and Project Management: Depending on the way roles and titles are defined within an organization, a systems engineer's responsibilities may overlap with what may be seen as 'project management' responsibilities. Even if there is no overlap, a systems engineer is expected to handle a variety of business and project management activities including accounting, budget, cost estimation, schedule, work breakdown, and profit. The systems engineer must also be cognizant of the business impact of technical decisions that are taken.

10 Forces that impact the Proficiency of Systems Engineers

The three most important forces that significantly impact the proficiency of systems engineers are *Experiences*, *Mentoring*, and *Education & Training*, in that order. These forces are generated by a combination of personal and organizational initiatives. The application of these forces is the primary way by which proficiencies of an individual are developed, as illustrated in Figure 10 below.

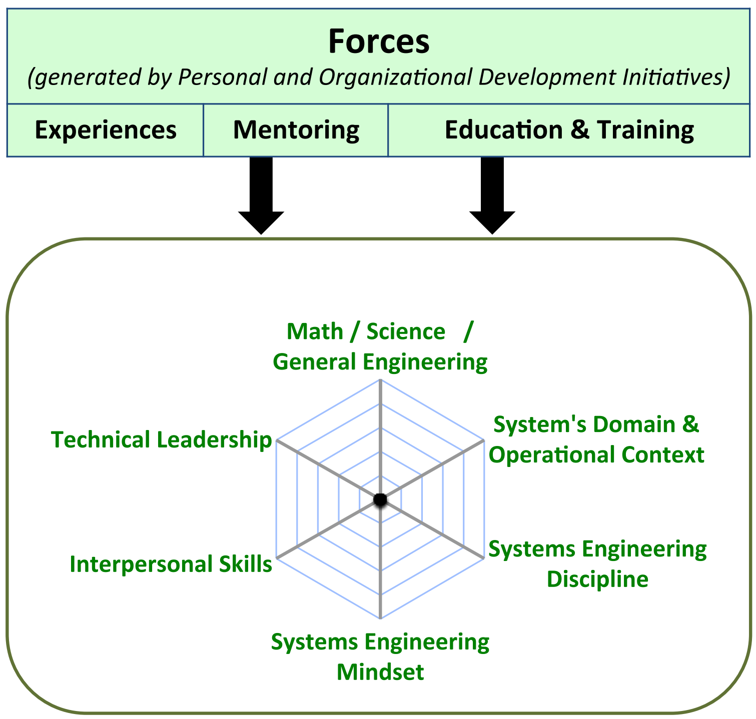


Figure 10. Forces and Proficiency

Insights into these forces that were identified from Helix data, and their relevance and importance for systems engineers, are discussed in Section 13.

10.1 Force 1: Experiences

Experiences are considered the most critical factor contributing to the development of proficiencies and to the overall growth of systems engineers. However, it is the characterization of these experiences that provides insight into how they impact proficiencies over time. Considering experiences as a force, each of these dimensions contributes to increasing one or more areas of proficiency. Experiences can also impact the personal characteristics of an individual. *Experiences*, as considered in *Atlas*, includes experiences along the following characteristics:

- **Relevance:** Every experience cannot be considered to be relevant to the development of systems engineers. A 'relevant' position is one that enables a systems engineer to develop the proficiencies critical to systems engineering. A 'systems engineering' position is one where the individual's primary focus was on SE activities.

- **Position:** Every systems engineer who is employed at an organization fills a position that is established by the organization; that organization also defines the roles and responsibilities to be performed. Helix considers position as a 'unit of measure' for experience, since most of the characteristics of experience is in the context of the position that is being held.
- **Chronological Time:** The amount of time spent in any particular position or in performing a role.
- **Number of Organizations:** The number of different organizations that an individual has worked at, not counting internal movement within an organization across departments or divisions, reflects the variety of experiences that one may possess. In large corporations that have multiple business units, or in situations where there are mergers and acquisitions, this number may not be a good indicator of the variety of experiences.
- **Organizational Sectors:** There are many differences in the general characteristics of an organization based on its sector. In *Atlas*, three organizational sectors are identified: government, industry, and academia.
- **Roles:** The 16 roles identified in *Atlas* are described in Section 8.
- **Lifecycle Phases:** Generic systems engineering lifecycle phases considered in *Atlas* are described in Section 9.5. The titles and descriptions of lifecycle phases or stages may vary across different systems engineering processes and frameworks available in literature or in use at an organization.
- **Systems:** There are many aspects to the types of systems on which a systems engineer could work. Working across these different categories provides valuable experience to an individual systems engineer.
    - **Domain:** This is the primary area of application for the systems being worked on. However, there are many domain categorizations; some domains also relate to industry sectors.
    - **Type:** Product systems, service systems, and enterprise systems are three major types of systems, depending on the nature and composition of the system of interest. System of systems is another paradigm in systems engineering, and could be a combination of one or more types of systems.
    - **Level:** A systems engineer could work on various levels of a system: component/element, subsystem, system, and platform or system of systems.

10.2 Force 2: Mentoring

Mentoring (or mentorship) is a relationship between two individuals: a mentor possesses more experience and knowledge and shares these with a mentee for the mentee's personal development. The effectiveness and derived value of the mentoring relationship is dependent on the individuals involved, but is also influenced by the organization which derives value out of a mentoring relationship as well.

10.2.1 What is Mentoring?

Mentoring means different things to different individuals and in different organizations. Common characteristics of mentoring are discussed below.

- Two individuals are involved in a mentoring arrangement: a mentor and a mentee (also referred to as a protégé).
- The mentor is usually *senior* when compared to the mentee in age, experience, and/or expertise.
- Primarily, the mentor *gives* and the mentee *receives*.
- The mentor-mentee relationship is a many-many relationship: a single mentor can have multiple mentees, and a single mentee can have multiple mentors – concurrently or spread over time.
- Mentor-mentee interactions typically happen over an extended period of time at varying frequencies.

There are also some differences and contradictions in the understanding of mentoring.

- Some use the term mentoring to describe any interaction with any co-worker in the organization that would provide any advice or guidance to handle the problem at hand.
- Some consider mentors to be synonymous with subject matter experts (SMEs) who are consulted for their expertise on an as-needed basis only. In contrast, some consider it mentoring only if the mentor is a senior person, and only if there are regular interactions between the mentor and mentee over an extended period of time.
- When the mentor and the mentee are of the same seniority in terms of age, years of experience, or level of expertise, some still consider it to be a mentoring relationship, while some others consider it to be a peer-peer relationship and not a mentoring relationship.
- Some distinguish between the concepts of coaching and mentoring: coaching is related to providing advice and guidance on solving a specific technical problem, while mentoring on the other hand, has neither a set beginning or end to the relationship nor is related to a specific event.

10.2.2 Mentoring Arrangements

Mentoring arrangements can either be formal or informal, depending on the level of engagement of the organization in establishing and sustaining the mentoring relationship. The two types of mentoring arrangements may be summarized as below:

- **Formal**: The organization plays an active role in establishing the mentor-mentee relationship, and also lays down guidelines for maintaining that relationship. Usually, organizations require that objectives and expectations for the mentor and the mentee be stated explicitly. The relationship and its progress tend to be monitored by the organization.
- **Informal**: The participating individuals establish the mentor–mentee relationship by themselves: either a mentor adopts a mentee or a mentee seeks out a mentor, and the relationship is established. Formal objectives or expectations are usually not stated explicitly, but it is considered good practice to establish these in some form at the start of the relationship. The organization plays a less active role in informal mentoring. It is upon the mentor and the mentee to establish and drive the relationship.

10.2.3 MENTORING FOCUS

Depending on what the mentoring is about, interviewees mentioned three types of mentoring:

- **Career Mentoring:** The mentor provides advice on career-related issues: helps identify career goals and the paths leading to that goal. The mentor could be from another group or division in the organization. Mentees are also groomed on management and leadership related topics.
- **Technical Mentoring:** The mentor typically provides advice on the technical details of the system being engineered. The mentor teaches lessons that are typically not found in textbooks and provides crucial insights on technical tools and processes. The mentor also acts as a subject matter expert, answering questions mentees might have on the subject, the system, or the program.
- **Organizational Mentoring:** While closely related to career mentoring, in organizational the mentor provides information about the organization: its culture, its procedures, and its policies. This is especially critical to a new employee.

10.2.4 BENEFITS OF MENTORING

In any typical mentoring arrangement, the mentor 'gives' and the mentee 'receives'. Therefore, such an arrangement is expected to be most beneficial to the mentee. However, there are benefits to the mentors as well. In addition, the organization also stands to benefit. Whenever an organization establishes a formal mentoring initiative, it usually expects to derive some benefit out the mentoring arrangements. However, the benefits to the mentee, to the mentor, or to the organization are conditional, and may not be taken for granted.

- **Benefits to Mentees**: A mentee is often a new or younger employee of the organization. Although mentees may have formal education or training that qualifies them for their jobs, there is much to be learned in the context of the organizational environment and culture and in the nature of the systems being engineered. A mentee could also be a senior engineer who is either new to the organization or has moved from another part of the organization, and whose experience and expertise could be in a different discipline or system. In either case, the mentee gains significantly through mentoring.
- **Benefits to Mentors:** A mentor is usually a senior, experienced engineer or manager who has spent more time in that part of the organization into which the mentee has entered, or in dealing with the type of system that may be unfamiliar to the mentee. Though the mentee stands to benefit the most, the mentor also benefits by mentoring, which tends to motivate the mentor to engage in a mentoring a relationship.
- **Benefits to Organization**: Effective mentoring not only benefits the mentees and mentors involved in the relationship, but also the workforce as a whole. When this happens, the organization at large benefits as well. One of the early motivations of the Helix study was the concern that a significant number of senior systems engineers would soon be eligible for retirement and whether organizations would be able to effectively manage the gap that would result. Mentoring is considered to be an effective way to help address this concern.

10.3 FORCE 3: EDUCATION & TRAINING

Education plays two key roles in the development of systems engineers:

1. It provides the foundation knowledge to support engineering-related work. Typically, this takes

the form of undergraduate education in an engineering discipline, technical field, or physical science.

2. Graduate level education is an avenue to develop more advanced skills, explore more in-depth knowledge, and help systems engineers grow as they move through their careers.

In addition to formal academic programs leading to undergraduate and graduate degrees, there are graduate certificates that individuals obtain, in an area that is closely related to their work. Some systems engineers go on to obtain doctoral degrees as well.

Systems engineers typically start their careers after obtaining an undergraduate degree, while graduate degrees may be obtained immediately after an undergraduate program or after a few years of professional work. Any formal degree directly improves proficiency in the relevant areas and categories. Any undergraduate degree in engineering typically provides much of the *Math/Science/General Engineering* proficiency in addition to the relevant categories under the *Systems' Domain & Operational Context* proficiency area. Graduate degrees add to relevant proficiencies; much of the formal systems engineering education happens at the graduate level.

While academic programs are typically offered by a university, there are a number of tailored training programs that organizations offer their employees. These trainings are more focused on building specific skills that are required for them to perform their work and are typically offered short-term. The topics vary widely across organizations, with some training focused on the technical aspects of systems development, other training focused on organization-specific approaches and processes, and still other training focused on leadership or interpersonal skills. Each type of training has a role in the development of proficiency.

Among the six proficiency areas in *Atlas*, *Math/Science/General Engineering*, *System's Domain & Operational Context*, and *Systems Engineering Discipline* may be considered to be 'hard' proficiencies at large, while *Systems Engineering Mindset*, *Interpersonal Skills*, and *Technical Leadership* may be considered to be 'soft' proficiencies at large. Formal education typically improves the hard proficiencies, but training could improve both hard and soft proficiencies.

In general, education or training results in an initial, single increase in proficiency. Additional changes over time are then the result of applying the knowledge or skills gained through this force in a real-world setting; i.e., through experiences utilizing the outputs of the education or training.

11 PERSONAL AND ORGANIZATIONAL CHARACTERISTICS

Personal characteristics and organizational characteristics can either enable or inhibit a systems engineer's ability to deliver value. They also influence the efficiency of the forces that impact the effectiveness of the systems engineer. However, it is also possible for the characteristics to be influenced by the forces, as illustrated in Figure 11.

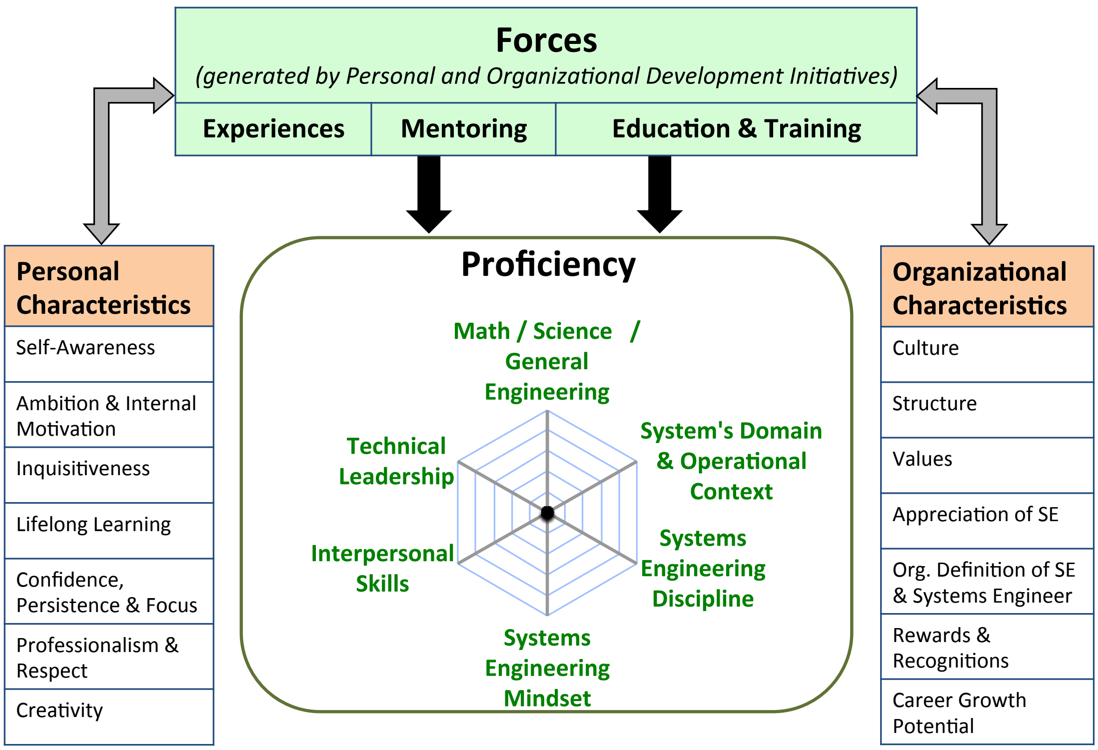


Figure 11. Forces, Proficiency and Characteristics

11.1 PERSONAL CHARACTERISTICS

Personal characteristics relate more to the personality of an individual. This implies three aspects:

- While forces that are generated through personal and organizational initiatives are expected to have a direct and significant effect on levels of proficiencies, the effect on personal characteristics is expected to be less significant.
- Personal characteristics are key enablers for forces to impact and grow the proficiencies. Conversely, the lack of some personal characteristics may slow down or even prevent the growth of some proficiencies.
- There is not enough evidence to state if personal characteristics are innate or learned. However, it appears that they can be influenced or improved.

Personal characteristics tend to be a differentiator between individual systems engineers. For example, two individuals with similar educational backgrounds and experiences undergoing the same training program may accrue different levels of benefits. Significant personal characteristics are identified below.

- **Self-Awareness:** The ability to self-reflect and become aware of one's own strengths, weaknesses, knowledge, and lack thereof.
- **Ambition and Internal Motivation:** The desire to reach high career positions, and the ability to draw motivation and energy from within in order to accomplish those high ambitions.
- **Inquisitiveness**: Possessing a high level of inherent curiosity, wanting to know more and have a 'hunger for knowledge'.
- **Lifelong Learning:** Always looking to learn and to keeping abreast with latest developments in related disciplines and systems, irrespective of seniority or position.
- **Confidence, Persistence and Focus:** Possessing the confidence to interact with stakeholders irrespective of their relative seniority or positions; the ability to stand firm and not give-up; and the ability to remain focused on the success of the overall system.
- **Professionalism and Respect:** Being professional in the conduct, mannerisms, and behaviors; and treating others with respect, recognizing that other experts may possess more knowledge and experience.
- **Creativity**: Combination of left brain – right brain, working together, bringing an artistic perspective to technical issues.

11.2 Organizational Characteristics

There are several characteristics of organizations that influence how difficult or easy it may be for a systems engineer to be effective. The primary characteristics are discussed below.

- **Culture, Structures, and Values:** While an organization's overarching culture, structure, and values have a much bigger impact than just on the systems engineering community, these factors certainly impact the ability of systems engineers to provide value to the organization.
  - A culture that values individual contributions over team contributions, for example, is a difficult environment for a systems engineer whose value is often realized through team coordination and interaction.
  - The way systems engineers are placed within the overall organization and how they are deployed to projects can impact performance.
  - Organizations that do state a value proposition for systems engineers tend to make systems engineering training more available and facilitate outreach with other disciplines.
- **Appreciation of Systems Engineering:** If an organization has no value proposition for systems engineers or if the value proposition for systems engineers is unclear, it raises uncertainties with individuals outside of the systems engineering community. These individuals do not understand what their expectations from systems engineers should be or what return on investment they should expect when they allocate a portion of their budget to systems engineering activities.
- **Organizational Definition of "Systems Engineering" and "Systems Engineer":** When an organization has an ambiguous definition of these terms – or no definition – it is an impediment to a systems engineer's effectiveness. In organizations with unclear or no definitions of these

terms, individuals outside of the systems engineering community form their own definition of what a systems engineer does based on their personal experiences with an often limited sample of systems engineers. When the title “systems engineer” is applied loosely within an organization, it can cause tension, as people do not have clear expectations of what value a systems engineer should truly bring to a project.

- **Rewards and Recognition:** Organizations tend to have a very common and generic annual performance evaluation system; there are no specific outcomes or objectives related to the value that systems engineers provide. Organizations need a consistent means of evaluating or rewarding systems engineering practice.
- **Career Growth Potential:** In organizations where the career path for a systems engineer is obscure, the discipline is seen as less appealing than other areas where career growth and opportunity is more clearly defined.

12 Career Paths

In addition to understanding the overall characterization of the elements of a systems engineer's career, it is helpful to look at the order and overlap of these elements, which can provide additional insights. Helix developed a way to visualize a career path, which is illustrated in Figure 12 below.

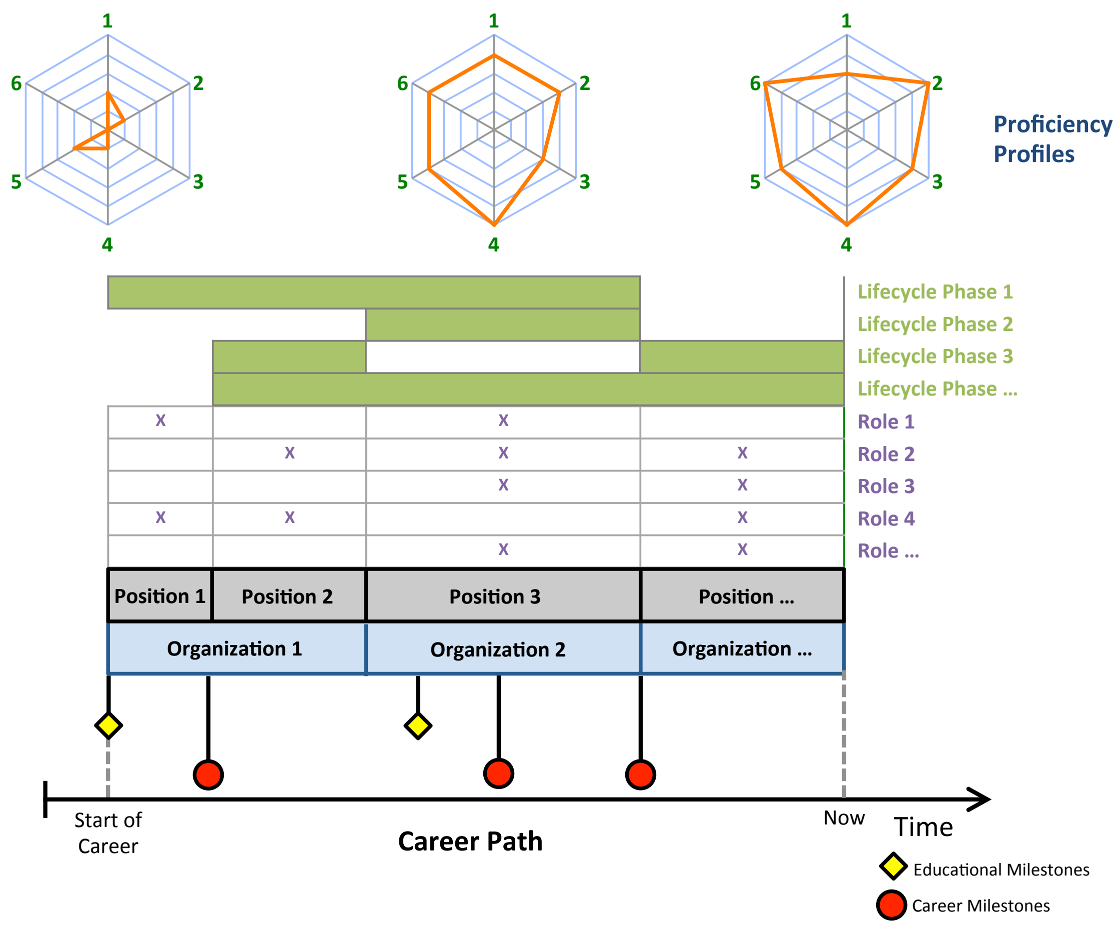


Figure 12. Visualizing a Career Path

The visualization pulls together the following elements of a career path:

- **Timeline:** Time is the dimension onto which all other elements of the career path are projected and visualized. The visualization helps understand the sequence, timing, and duration of various elements of the career path, offering valuable insights for developing the careers of systems engineers.
- **Educational Milestones:** The career of an individual typically begins when an undergraduate degree (or in some cases, a higher degree) is obtained. When, in which disciplines degrees are obtained, and how they impact other elements of the career path can be observed.
- **Career Milestones:** Significant milestones in terms of types of systems engineering positions,

such as first leadership position, chief systems engineer, or program engineer, etc.

- **Organizations:** The variety of organizations and the time spent in each of those organizations can provide interesting insights, particularly if the organizations vary in terms of sectors, key domains, or other factors.
- **Positions:** The number and duration of all positions held across organizations are captured in the career path. How duration and educational qualifications affect positions can be observed.
- **Roles:** The roles performed in each of the above positions perhaps offer the most interesting insights into a career path. An individual is likely to perform more than one role in any particular position, but those roles typically vary as one's career progresses. Some roles performed earlier in one's career may no longer be performed, and there may newer roles that one plays later in her career. The types of roles performed concurrently offer insights into each position.
- **Lifecycle Phases:** The lifecycle phases experienced during each of the above positions are indicated along the career path. The duration and sequence of the lifecycle experiences indicates the exposure that an individual possesses. Similarly, some roles may be more relevant to particular lifecycle phases.
- **Proficiency Profiles:** The level of proficiency can be profiled at any point in the career with respect to the *Atlas* Proficiency areas. Possibly the most difficult to depict accurately across the career, the proficiency profile can be mapped onto the roles and positions that one performs. This visualization also helps to show, and how education and experiences influence proficiency.

The career path visualization currently does not include mentoring or training, but gathering all elements into a single visualization provides a holistic view of the entire career of an individual systems engineer. When multiple career paths of different individuals are visualized, patterns can be observed that can offer interesting insights for career development of future systems engineers.

PART 3

BUILDING *ATLAS* THROUGH HELIX RESEARCH

Atlas, which was elaborated in Part 2, is the primary product of Helix research. A grounded-theory based approach, applying a variety of qualitative and quantitative research methods, was used to build *Atlas*.

During the semi-structured interviews conducted by Helix for data collections, two themes were always explored with systems engineers, triggered by questions that were phrased along these lines:

- “What makes you an effective systems engineer?”
- “How did you become good at these things?”

The elaborate responses from the interviewees to these questions and the subsequent discussions, provided rich data that was then analyzed in detail.

Responses to the first question contributed to building the proficiency model as well identifying personal characteristics; responses to the second question contributed to the identification of forces and how they impact proficiencies.

How *Atlas* was built from these responses, as well as additional insights from those responses, are elaborated here in Part 3:

- Section 13 describes why the three forces mentioned in *Atlas* were chosen and how they impact proficiencies. This section provides a background to the *Atlas* forces described in Section 10 of Part 2.
- Section 14 describes the personal characteristics identified in *Atlas*, and explains the rationale for identifying these characteristics from Helix data. This section provides a background to the personal characteristics described in Section 11 of Part 2.

The areas, categories, and topics of the *Atlas* proficiency model were presented in Section 9. However, additional insights into the *Atlas* model are not included in the current report on *Atlas 0.5*. The Helix team is currently analyzing data collected through Helix interviews in 2015 towards deepening the understanding of the *Atlas* proficiencies, defining the scales for evaluating proficiency levels, identifying relationships between the proficiency areas and categories, and generating specific recommendations for growing *Atlas* proficiencies to desired levels. These results will be included in subsequent reports on *Atlas*.

13 EXPLORING THE FORCES

When Helix interviewees discussed ways in which the proficiencies of systems engineers could be developed based on how their own proficiencies developed over their careers, everyone mentioned *Experiences* as the most important force. *Mentoring* was the next important force that could enable systems engineers to increase their proficiencies. The third significant force mentioned was *Education & Training*.

13.1 ANALYSIS OF EXPERIENCES

When asked for their recommendations on how systems engineers *should* grow and mature, 62% of the feedback captured in excerpts focused on the need for breadth of experiences and indicated this was critically important for growth. While 24% of the excerpts focused on the required depth of experiences in a particular discipline, technology, or domain, 23% of the excerpts on depth also described the need to balance "enough" depth with breadth of experiences.

13.1.1 RELEVANT EXPERIENCES

In Helix, the experiences of an individual that are considered for analysis are only the ones that are 'relevant' to systems engineering – that is, those that enable the proficiencies critical to systems engineering to be developed. It was observed in the careers of interviewees that the first few positions in their careers may have developed their professional skills, but did not specifically develop their systems engineering skills.

A 'systems engineering' position is a 'relevant' position where the primary focus is on systems engineering activities, irrespective of the title. Many interviewees identified their first systems engineering position in hindsight, since they were not aware at that time that they were performing systems engineering activities, or the organization did not officially recognize systems engineering activities.

Understanding the timing of the first relevant position and first systems engineering position enables a common 'starting point' to be defined for systems engineers, which then makes it easier to compare or develop career paths. However, it was not always easy to identify the duration of relevant experiences in an interviewee's career since they were discussing initial stages of their career that could be decades long. Figure 13 below illustrates the years of relevant experience of systems engineers in the Helix sample.

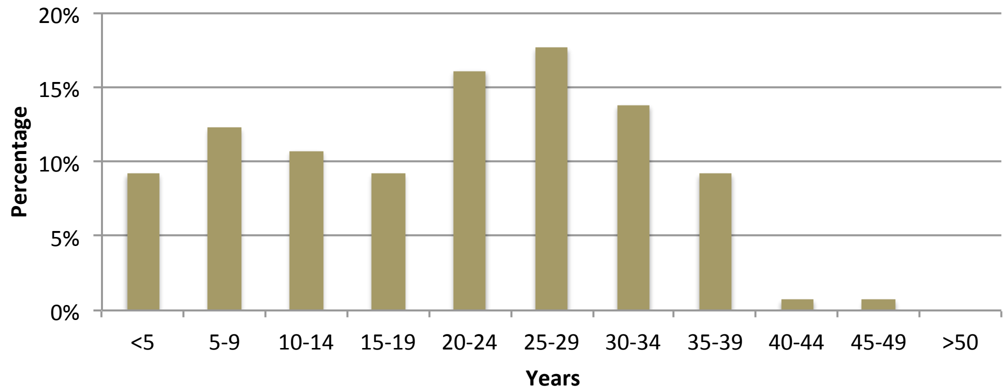


Figure 13. Years of Relevant Experience for The Systems Engineers in The Helix Sample

The distribution in Figure 13 shows that over two-thirds of the sample (68%) have 20 years or more of relevant experience, while 17% of systems engineers have less than 10 years of relevant experience. Years of experience cannot be directly correlated to proficiency, but clearly a longer range of relevant experiences may provide a systems engineer with more opportunities to build proficiencies. The years of relevant experience segregated by seniority is illustrated below in Figure 14. It must be noted that years of relevant experience does *not* necessarily correspond to the age of the systems engineer or the duration of their entire careers.

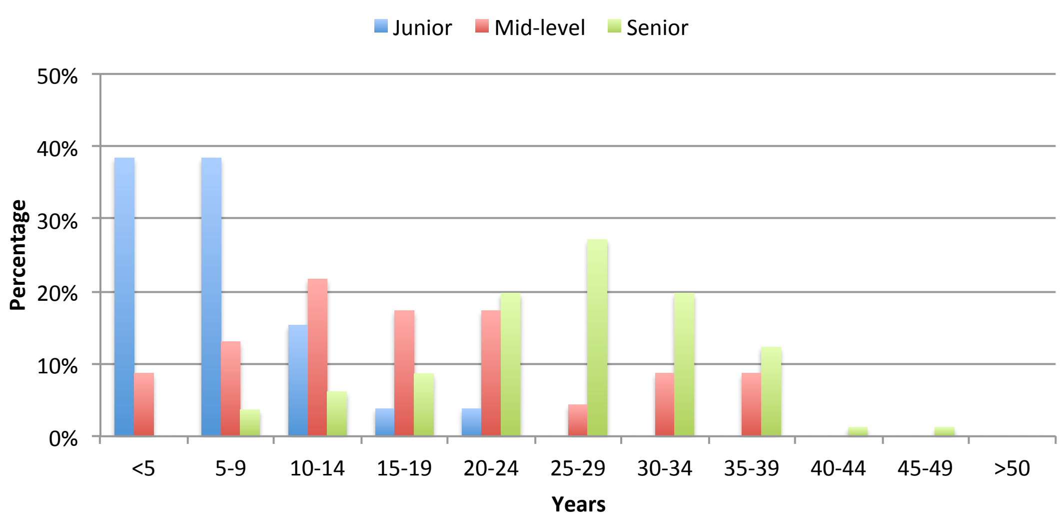


Figure 14. Years of Relevant Experience, by Seniority

The following observations can be made from Figure 14:

- In the range of 5 to 24 years of relevant experience, there are interviewees who were at all levels of seniority.

- Over 75% of junior systems engineers have fewer that 10 years of relevant experience.
- Among mid-level systems engineers, about 70% have between 5 and 20 years of experience.
- There are mid-level systems engineers with over 30 years of experience, but they have not yet taken on leadership roles in systems engineering that would make them senior systems engineers.
- Senior systems engineers have between 8 and 47 years of experience, but with nearly two-thirds (64%) having between 20 and 40 years of experience.
- Senior systems engineers with over 40 years of experience are individuals who are eligible for retirement, but who stated in their interviews that they still enjoy their work and see no reason to leave.
- Senior systems engineers with 10 or less years of experience tend to be individuals who were spoken of by managers and other interviewees as "high potential" or "individuals to watch".

The most significant observation from Figure 14 is that 'years of relevant experiences' is not a reliable metric to identify the seniority of a systems engineer; and for this reason, has not been included as a criterion for distinguishing the seniority of systems engineer in Table 2 in Section 7.

The total number of years of relevant experience or the number of years spent in any particular position or role has a direct impact on the depth or level of relevant proficiencies. However, even though more time would improve familiarity, it is also possible that the impact diminishes or stagnates over time. Hence, considering just chronological time is not valuable in understanding the impact on proficiencies.

13.1.2 Experiences Across Organizations

When an individual works within a single organization for a long period of time, she learns and internalizes the organization's processes for systems engineering, builds a network of peers that they leverage to better perform systems engineering, and how to operate within the organization. All of these things contribute to a systems engineer's proficiency and effectiveness. However, moving to a new organization provides opportunities for gaining new proficiencies. Exposure to different processes or systems engineering approaches helps systems engineers better understand the conditions appropriate to different approaches, and improves their ability to tailor processes and approaches as appropriate. Working within a new culture provides opportunities to better understand the impacts of culture on the overall effectiveness of systems engineers. Though transitions might be difficult, they can provide valuable experiences.

Figure 15 shows the distribution of total number of organizations worked across the sample, divided by seniority.

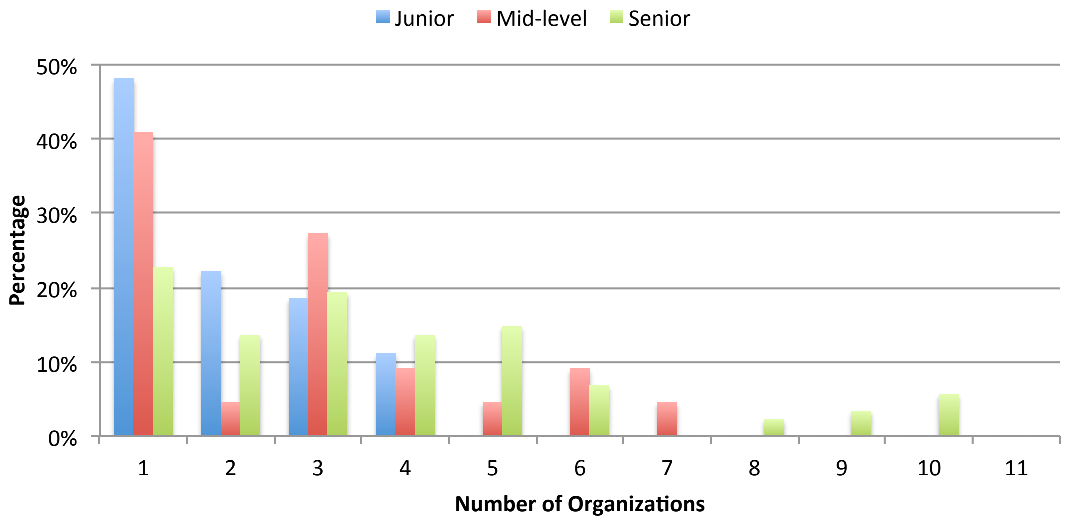


Figure 15. Experiences across Organizations, by Seniority.

The following observations can be made from Figure 15:

- Only the most senior systems engineers in the sample have worked in 8 or more organizations, as they generally have had the longest careers and, therefore, the most opportunities for movement between organizations.
- Nearly 50% of the junior systems engineers have worked in only one organization, as their careers have been generally much shorter.
- Over 40% of mid-level systems engineers and over 20% of senior systems engineers have only worked within a single organization. Those who fall within this category explained that they understood the organizational context so well and are satisfied with that context, that they see no need to make changes.

13.1.3 Number of Organizational Sectors

In terms of individual experiences, it is useful to understand whether an individual has worked for government, industry, or academic organizations, or a combination of these. At the time of their interview, 29% of the sample was currently working in government and 71% was currently working in industry. No interviewees in the Helix sample were currently working in academia alone.

In general, government systems engineers tend to oversee work done by systems engineers in industry as opposed to having the same direct responsibility for a system as seen in industry. There was one government organization in the current sample in which systems engineers reported directly performing hands-on systems engineering development work rather than primarily overseeing the work of others.

The different types of positions in the different sectors provide opportunities to develop new proficiencies – perhaps in new domains or operational contexts, or perhaps in new ways that systems engineering would be applied. However, some individuals stated that it might be difficult to transition between sectors because the overall ways in which the organizations operate, the processes used, and the cultures embedded, may be nearly polar opposites. This may mean that some skills become either obsolete or even harmful in a new organizational sector.

Moving across organizational sectors provides the opportunity to build new proficiencies. While this may be true for movement between any organizations, interviewees indicated that the impact is significant when moving between organizations in different sectors.

Figure 16 shows the distribution of the organizational sectors that Helix interviewees have worked in so far during their systems engineering relevant careers.

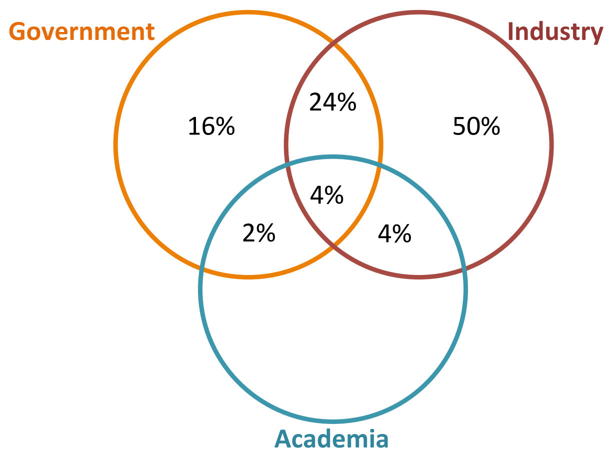


Figure 16. Variety of Organizational Sectors Experienced by Systems Engineers

The following observations can be made from Figure 16:

- 50% of the systems engineers in the sample have worked only in industry during their careers, while 16% have worked only in government.
- Almost a quarter have moved between industry and government during their careers, and in both directions; there is no pattern observed in the direction of movement. Interestingly, individuals who have moved in either direction often cite the same reasons for the movement: stability and a perceived opportunity for increase in technical responsibilities.
- Only 4% of the interviewees have industrial and academic experience, while only 2% have government and academic experience.
- There were a few individuals (4%) who had experiences in all three sectors.

13.1.4 Experiences Across Roles Played

Atlas identifies 16 roles for systems engineers, as listed in Table 3. The roles that an individual actually gets to play are dependent on the positions she occupies as defined by the organization. It is common for multiple roles to be performed within a single position. Single-role positions are typically encountered early or late in one's career. When found early in the career, systems engineers focused on detailed work in one role, but when found late in the career, systems engineers performed in roles such as management or teaching. In order to be effective in those late-career roles, earlier experiences in a variety of roles are useful.

Figure 17 shows the distribution of total number of roles played by systems engineer across the sample, divided by seniority.

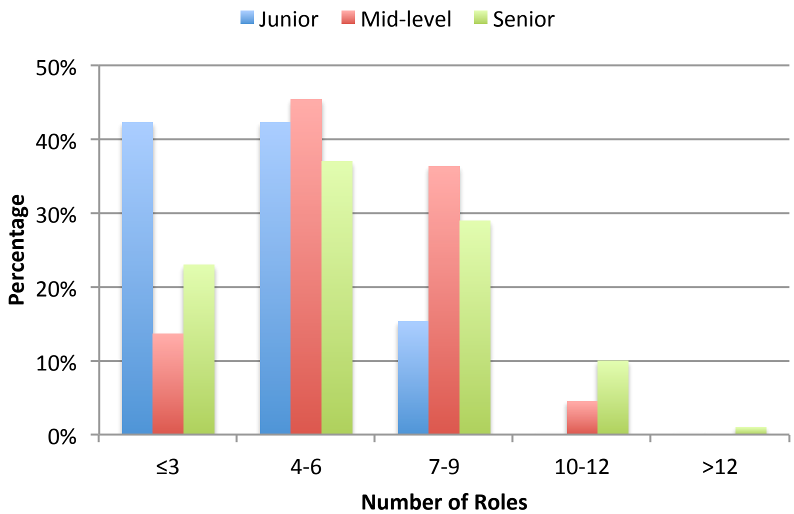


Figure 17. Total Number of Roles Played by Systems Engineers, by Seniority.

The following observations can be made from Figure 17:

- Over 40% of junior systems engineers have played up to 3 roles.
- Over 50% of junior systems engineers have played 4 to 9 roles. This is largely due to junior systems engineers participating in rotational assignments offered by organizations to new hires or newly-selected systems engineers.
- Over 75% of mid-level systems engineers have played 4 to 9 roles. Again, many of these individuals participated in rotational programs as junior systems engineers, increasing the number of roles played.
- Some senior systems engineers have played more than 12 roles across their entire career; almost all of these were also chief systems engineers.

Figure 17 also shows that there is no consistent grouping that can be used to differentiate the seniority levels of systems engineers. For this reason, 'number of roles played' is not included in the criteria listed in Table 2.

Figure 18 shows the percentage of systems engineers of the sample who have performed the various roles identified in *Atlas*. It may be noted that when this chart was created, the role of 'Classified Ad' (Sheard 1996) was still being considered, and the role of 'Systems Engineering Evangelist' was not yet included. Identifying those who have played the role of 'Systems Engineering Evangelist' requires another mapping of interview data with the career path analysis; it is not something that can be gleaned from resumes. Therefore, this additional analysis will be published in future versions of *Atlas*.

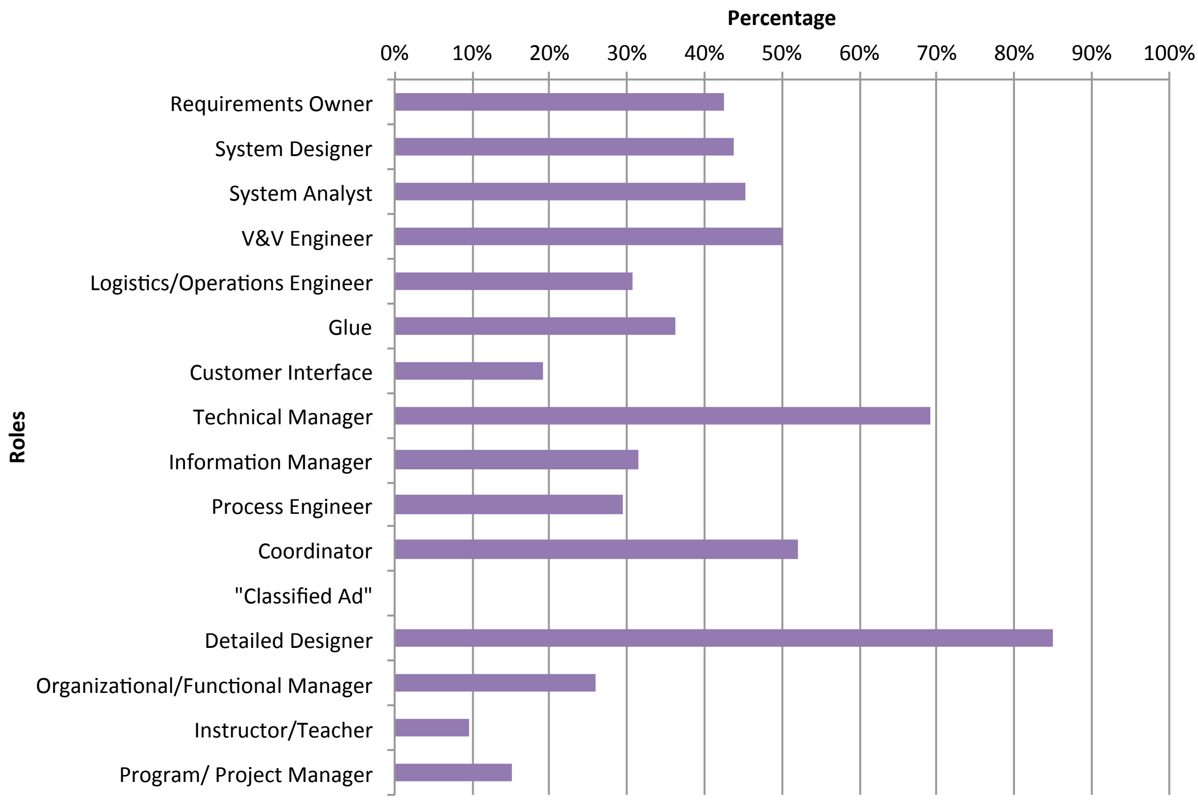


Figure 18. Distribution of Roles Played by Systems Engineers in The Helix Sample

Based on Figure 18 and other analyses on roles from interview data and resumes of interviewees, the following observations can be made:

- It was more common that multiple roles were played within a single position than only one type of role was played within a single position.
- 85% of systems engineers have played the role of detailed designer, most often in their first few positions. This is primarily because many individuals come to systems engineering from other engineering disciplines.
- The roles *Requirements Owner*, *System Designer*, *System Analyst*, *V&V Engineer*, and *Operations and Logistics Engineer* tend to occur earlier in a systems engineers' career, particularly when they occur as single roles in a position.
- The roles *Technical Manager*, *Glue*, *Coordinator*, *Customer Interface*, and *Process Engineer* tend to occur later in a systems engineer's career.
- It was also common for systems engineers to *take* on additional roles later in their careers that may not traditionally be considered "systems engineering" roles. These roles include *Organizational/Functional Manager* – often within a systems engineering organization; *Program/Project Manager* – either concurrent with or separate from systems engineering responsibilities; and *Instructor/Teacher* – specifically of systems-related training or education.

13.1.5 Experiences across Lifecycle Phases

A variety of experiences across systems lifecycle phases provides critical experience to an individual, who gets to learn and 'feel' the impacts of decisions – the intended and unintended consequences of early-lifecycle decisions on the system during later lifecycle phases. *Atlas* uses the generic systems engineering lifecycle phases described in Section 9.5.

Figure 19 shows the distribution of total number of lifecycle phases experiences by systems engineers across the sample, divided by seniority.

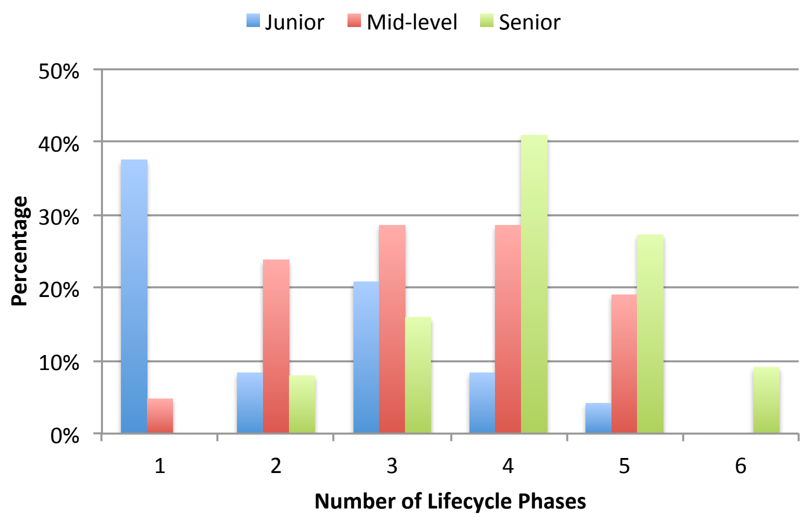


Figure 19. Total Number of Lifecycle Phases Experienced by Systems Engineers, by Seniority

Figure 20 shows the order in which systems engineers in the Helix sample were exposed to the various lifecycle phases, along their career.

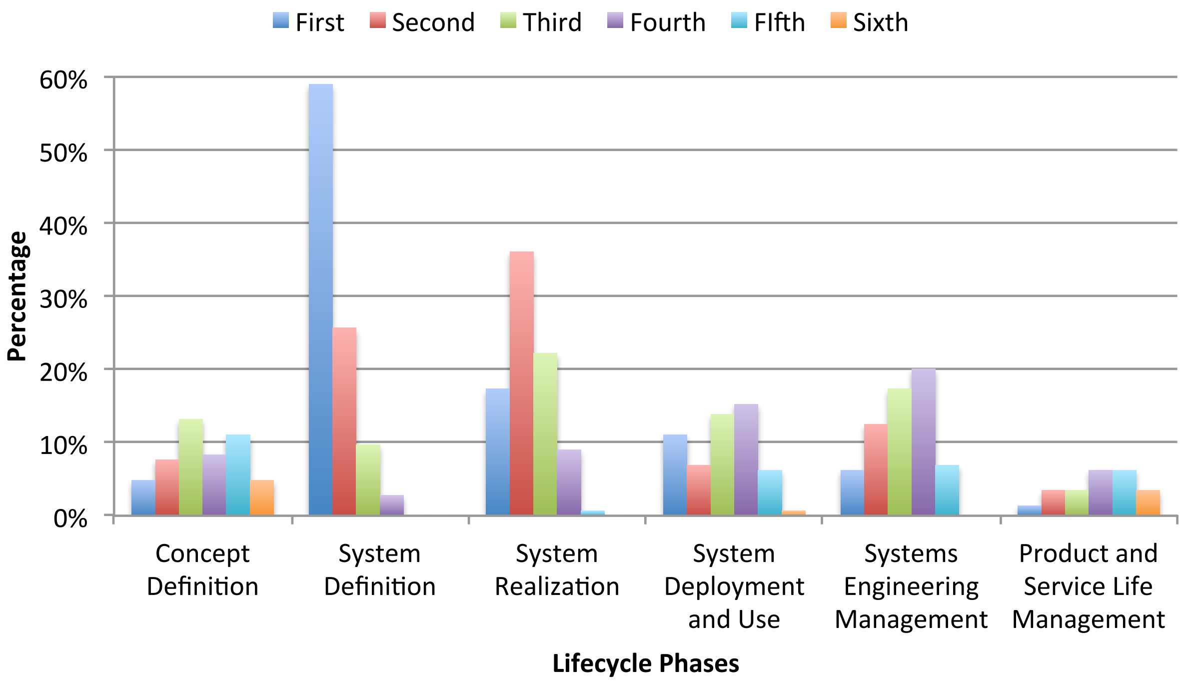


Figure 20. Order of Exposure to Lifecycle Phases, Experienced by Systems Engineers

The following observations can be made from Figure 19 and Figure 20:

- Only about 8% of the systems engineers in the Helix sample have had exposure to all lifecycle phases, all of whom were senior systems engineers.
- Over 50% had experiences in 4 or 5 phases of the lifecycle. The majority were senior or mid-level systems engineers. The few junior systems engineers who had seen this level of variety in the lifecycle had participated in rotational programs.
- The least commonly seen activity is *Product and Service Life Management*, which deals primarily with late lifecycle system activities. This may be a reflection of the organizations currently in the Helix sample, that tend to be more focused on early lifecycle activities.

13.1.6 System Domain, Type, and Level

System Domain

The Helix team did not encounter a standard set of domains for systems engineering application in a review of the literature. The words used by interviewees to describe the domains in which they had worked were captured. Based on this, the Helix team used the North American Industry Classification System (NAICS) to create reasonable groups of domains. Experiences across these domains, divided by seniority, is illustrated in Figure 21. This distribution is only a reflection of the systems engineers currently in the Helix sample.

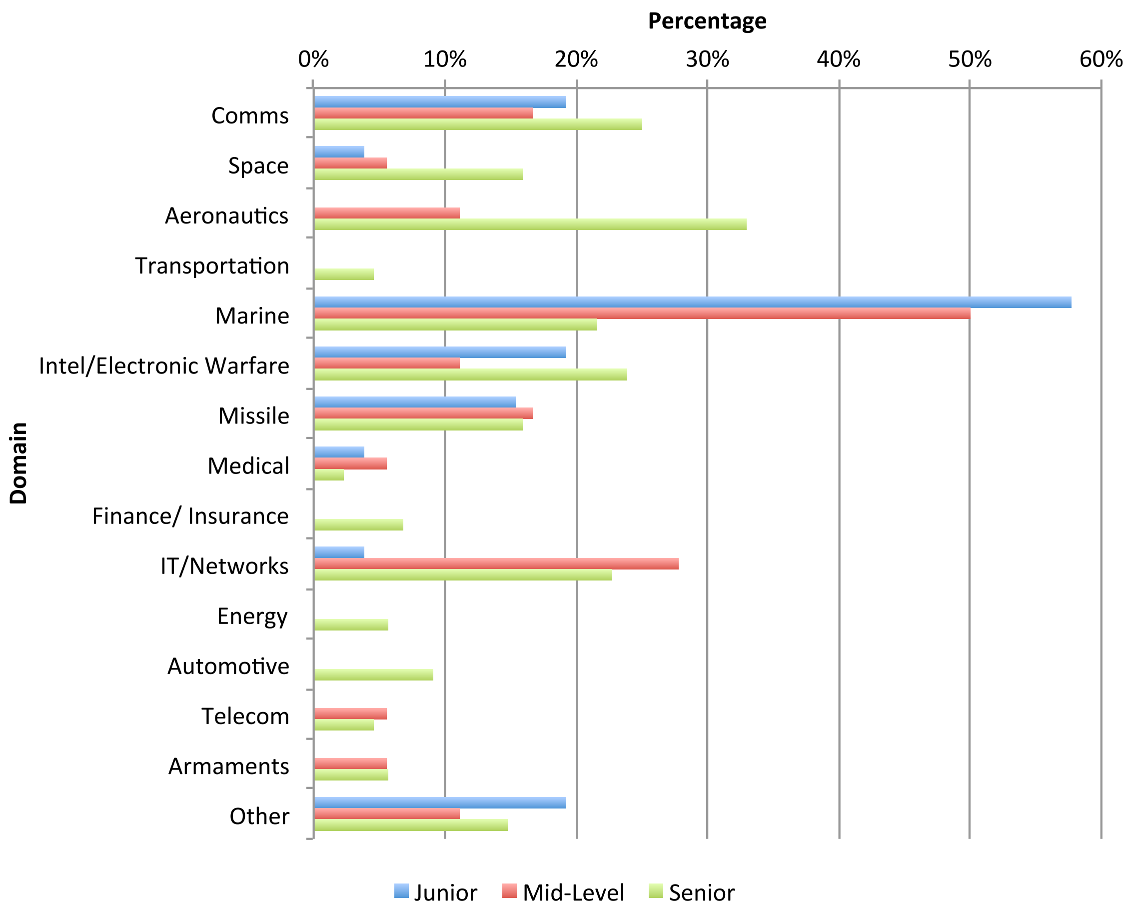


Figure 21. Experiences of Systems Engineers across System Domains, by Seniority.

System Type

All systems engineers in the Helix sample have worked on product systems during their careers, as illustrated in Figure 22; less than 20% have worked on service systems, and about 25% have worked on enterprise systems. Only senior systems engineers reported having responsibilities at the system of systems level. Because most of the experiences discussed during Helix interviews were on product systems, no insights can be highlighted that focus specifically on service or enterprise systems. However, it was indicated that working on service or enterprise systems required a much richer understanding of business in general – business processes, finance, and the overall goals and drivers of that particular business. It was an area where educational elements such as an MBA might be very useful.

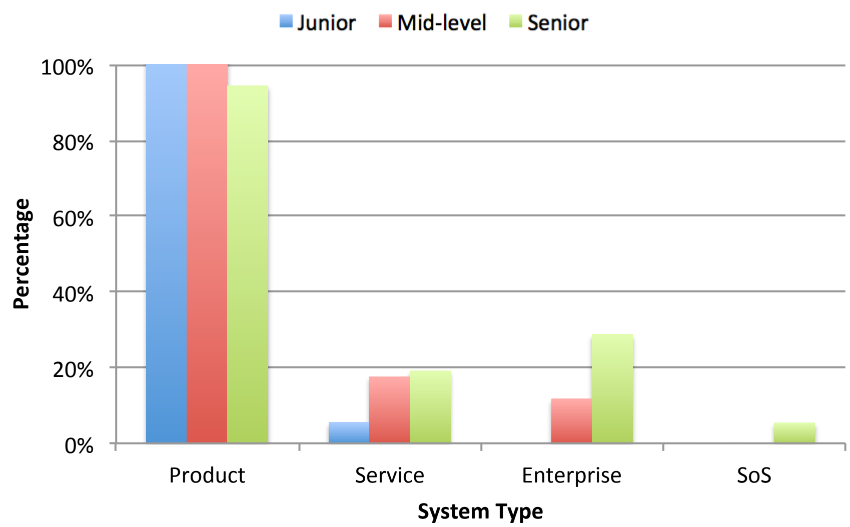


Figure 22. Experiences of Systems Engineers across System Types, by Seniority

System Level

Identification of system levels tends to be relative, depending on the size and complexity of the system, and on the system level at which the organization is engaged. Based on what could be identified from the Helix sample, Figure 23 shows the experiences across systems levels, divided by seniority.

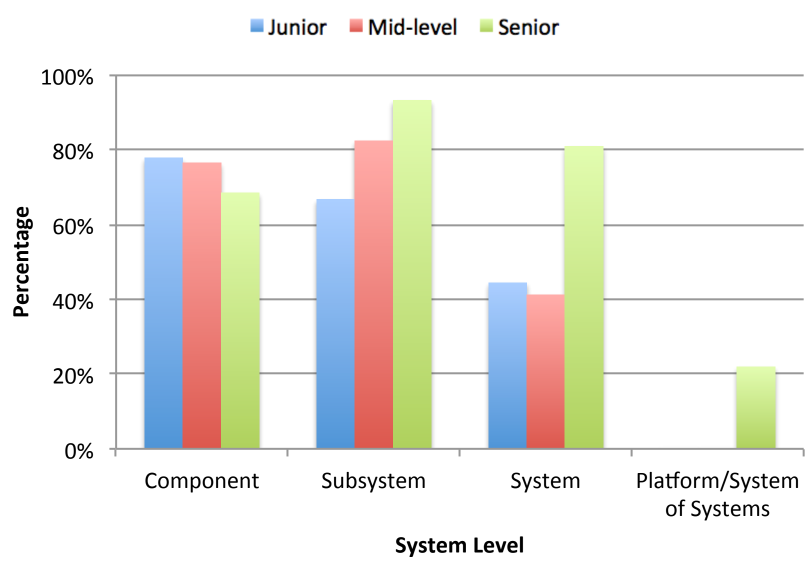


Figure 23. Experiences of Systems Engineers across System Levels, by Seniority

The following observations can be made from Figure 23:

- Not all systems engineers have worked at the system level. However, many of the systems discussed during interviews were large and complex. When a systems engineer worked on subsystems, it could be complex enough to be considered the "system level" by a different organization, but was still counted a 'subsystem' level experience based on the language used by the interviewees.

- Junior and mid-level systems engineers make up almost a 1/3 of the sample; and so, some of them have not yet had responsibilities at the system level.
- Not all individuals have had responsibilities at the component level. This may be a result of what an individual reported in the resume or interviews versus what their full range of experiences have included.

Experiences at different system levels were generally linked with development of different types of proficiencies.

- Experiences at the **component level** were generally associated with development of proficiencies in *Math/Science/General Engineering*, as these were often experiences applying engineering disciplines at the detailed level. In addition, it was common for early leadership positions to be at a small scale – component or perhaps a small subsystem – and these experiences helped to develop proficiencies in *Technical Leadership*.
- Experiences at **subsystems level** often created opportunities for engineers to better understand the implications of the environment or concept of operations on the operation of the system, helping them develop higher proficiencies in *System's Domain and Operational Context*. Because subsystems require the interface and interaction of multiple components, they also provide more opportunities for understanding and growing proficiencies in *Systems Engineering Discipline* and *Systems Engineering Mindset*.
- At the **system level**, systems engineers were generally taking on higher levels of responsibility and working on larger teams – further growing their proficiencies in *Interpersonal Skills* and *Technical Leadership* while also requiring them to further grow in their understanding of *Systems Engineering Discipline* and the application of the *System's Domain and Operational Context*. Systems engineers often stated that a higher proficiency in *Systems Engineering Mindset* was required in order to be effective at the system level.

13.2 Analysis of Mentoring

The topic of mentoring was discussed with 120 Helix interviewees; and among them, 80 discussed the mentoring that they had received or provided during the careers.

13.2.1 Engagement in Mentoring Arrangements

Figure 24 indicates the type of mentoring received by interviewees anytime in their career. Among the 80 interviewees used for this analysis, 89% had received some type of mentoring (11% did not receive any type of mentoring). Within this, 12% had received formal mentoring only and 36% had received informal mentoring only. Among the 23% who had received both formal and informal mentoring, informal mentoring was more valuable than the formal mentoring they had received.

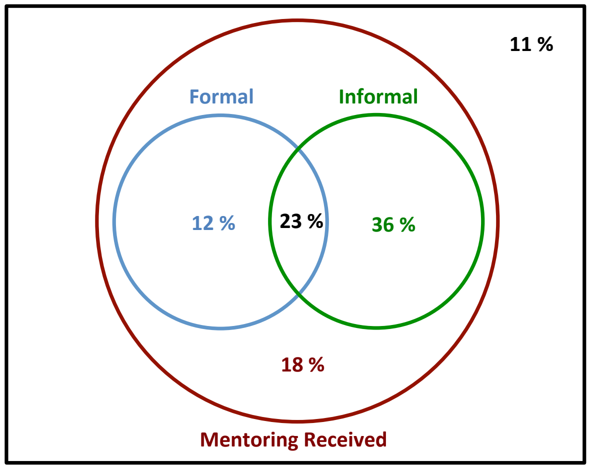


Figure 24: Types of Mentoring Received by Interviewees

Figure 25 indicates the mentoring arrangements where interviewees were the mentors. Most of the 80 interviewees had indicated that they had been mentors at some point in their careers, and many were active mentors during the time of the interview. It was rare to find an interviewee who was a mentor in the past but was not mentoring anyone at present, and those who had found much value in the mentoring they had received were eager and willing to mentor others. This indicates that interviewees cease to be mentees at some point in their careers, but rarely cease to be mentors. Among 80 interviewees used for this analysis, only 10% had not mentored anyone. In the 90% who have provided some form of mentoring to others, 4% had been a formal mentor only and 51% had been informal mentors only, but 15% had been both formal and informal mentors. Interviewees preferred to mentor others, especially those junior to them, in an informal arrangement rather than in a formal arrangement set up by the organization.

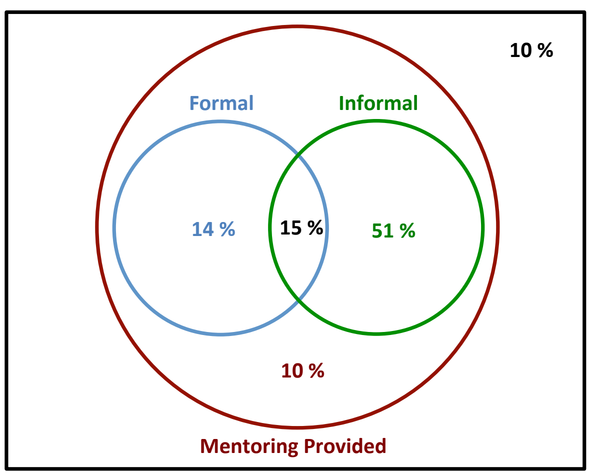


Figure 25: Types of Mentoring Provided by Interviewees

13.2.2 Formal vs. Informal Mentoring

In all the mentoring related discussions, the biggest debate was on which mentoring arrangement was more effective: formal or informal. Both these forms of mentoring have their own pros and cons; and in many cases, it appeared that the challenges and limitations in one type of mentoring were easily resolved by the other. Though the interviewees expressed their strong preferences, there was no clear winner, nor was there meant to be one. Either of these could be effective, depending on the organizational policies and culture, or depending on the specific mentor and mentee involved in the relationship. In any case, both formal and informal mentoring arrangements have their place in any organization and in any mentor-mentee relationship. As one interviewee put it, "its not about formal or informal as long as there is a commitment from me, the mentor, to spend the time to answer the questions, and commitment from [the mentee] to put some effort in". The views expressed by the participants are tabulated below.

Table 5. Comparison between Aspects of Formal and Informal Mentoring

Topic	Formal Mentoring	Informal Mentoring
Visibility to Organization	Organizations tend to have full visibility into the mentoring arrangement and how it is working out for the mentor and the mentee.	Organizations are usually unable to keep track of a mentoring arrangement, and may even be unaware that such arrangements exist.
Mentor-Mentee Pairing	Organizations enable the mentor-mentee pairing: in some cases, it is forced; and in some cases, some flexibility in choice is given. There is the possibility of "wrong" selection or pairing that may not last long. In some cases, organizations enable mentors and mentees to establish a mentoring arrangement, but do not explicitly make the pairing.	Mentors and mentees tend to establish the relationship by themselves, usually upon the request of the mentee. These relationships tend to last longer, since the mentees have the flexibility to choose the mentor that they are comfortable with.
Mentor Engagement	Not all senior engineers are good mentors; and not all potentially good mentors are willing to be one. If they are forced into a relationship against their preference, they tend to be ineffective and unwilling. "Some mentors don't interact at all," said one interviewee.	Mentors usually enter into a mentoring relationship by their own choice and therefore tend to be more engaged.
Mentee Responsibility	The organization plays a part in establishing a mentoring arrangement, and this works for introverted mentees. However, it could also make mentees more passive than active.	The mentees must find a mentor and drive the relationship; "I think the mentee has to want it more than the mentor," said one interviewee. More introverted mentees may find it difficult to seek a mentor and to ask them questions, while extroverted mentees find it easier to "go bug them and pick their brains".

Topic	Formal Mentoring	Informal Mentoring
Goals and Objectives	The organization lays down expectations for a mentoring relationship and could also provide guidance on establishing goals and objectives. This is helpful to the mentee in particular, and tends to be more impactful.	There may be an informal understanding of some overall goals and objectives between the mentor and the mentee, but there is no requirement to establish them.
Mentoring Load	Mentoring can be burdensome, mechanical, and obligating. It is possible to "go through the motions" without any beneficial engagement.	Mentoring is usually a pleasure for both the mentor and the mentee since they both tend to be "willing and eager". "If you try to formalize or institute a mentoring program, it feels awkward" said one interviewee.

13.2.3 Benefits of Mentoring

In any typical mentoring arrangement, the mentor 'gives' and the mentee 'receives'. Therefore, such an arrangement is expected to be most beneficial to the mentee. However, there are benefits to the mentors as well. In addition, the organization also stands to benefit. Whenever an organization establishes a formal mentoring initiative, it usually expects to derive some benefit from the mentoring arrangements. However, the benefits to the mentee, to the mentor, and to the organization are conditional, and may not be taken for granted. The discussions presented in this section also establish the need for mentoring.

Benefits to Mentees

A mentee is often a new or younger employee of the organization. Although mentees may have formal education or training that qualifies them for their jobs, there is much to be learned in the context of the organizational environment and culture and in the nature of the systems being engineered. A mentee could also be a senior engineer who is either new to the organization or has moved from another part of the organization, and whose experience and expertise could be in a different discipline or system. In either case, the mentee gains significantly through mentoring:

- **Relationship with Mentor**: The biggest benefit to mentees of mentoring is the relationship they establish with their mentors over the span of their careers; most other benefits of mentoring are enabled through the mentor. Mentors become key enablers for mentees: they look after them; they are their biggest advocates and champions; they help identify strengths; and they become critical factors for success in their careers. On the professional achievements he has accomplished, one interviewee said, "Without my mentor, it might not have happened." Not everyone is lucky to have a mentor early in their career, and some interviewees stated that their careers could have been different if they had had a mentor. When asked what he would do differently if he were to re-start his career, one interviewee answered, "I would get a mentor."
- **Increased Effectiveness**: Most interviewees identified mentoring as a critical factor that increases the effectiveness of systems engineers. The lessons that they learn and knowledge that they acquire through mentoring is less effectively attained through other means. Interviewees also noted that through mentoring, the learning is quicker and more effective when compared to other means.

- **Career Advancement**: Through their mentors, employees often get exposed to opportunities within the organization that may not be visible otherwise. Mentors tend to point the mentees in the 'right direction' and enable them to move in that direction. In hindsight, such moves have been significant contributors for the career advancement of many interviewees.
- **Valuable Lessons**: During mentoring, mentees often receive important lessons from their mentors, which have made a significant impact in their careers. Many interviewees quoted their mentors during the interviews; and how something they learned from their mentors shaped their perspectives. Mentees also learn how to cope with challenges, how to deal with complexity, and also receive tactical guidance from Mentors on "how to do this job well." Mentees also acquire critical insights into the system or program that help them over their career.
- **Strong Networking**: Building a strong professional network is key to any employee. Through mentoring, mentees get exposed to many senior engineers and others in the professional network of their mentors. In addition, mentors could also rise to very senior positions within the organization and continue to contribute to the network of the mentee.

Benefits to Mentors

A mentor is usually a senior, experienced engineer who has spent more time in that part of the organization into which the mentee has entered, or in dealing with the type of system that may be unfamiliar to the mentee. Though the mentee stands to benefit the most, the mentor also benefits from mentoring which tend to motivate the mentor to engage in a mentoring a relationship.

- **Professional Gratification**: "If I can get people to do better at what they're doing, that's an incentive for me to stick around" said one interviewee who was close to retirement; "I mentor people just because I want to," said another. Many considered mentoring to be an important part of their jobs, irrespective of the organizational acknowledgement of it. "Helping the stars" and "teaching the young'uns what to do" seems to be motivation enough for the mentees. One interviewee even said about those he mentors, "their work portrays my effectiveness".
- **Organizational Recognition**: In organizations where mentoring is acknowledged, mentors get recognized for their efforts. It is also typical for mentoring to be featured in the annual performance reviews of the mentors. Being a mentor increases the visibility of an employee within the organization and also helps in career advancement.
- **Reduced Workload**: Some mentors considered mentoring to be a means of reducing their workload. When a mentee is able to share the load, "I don't have to work as many hours," said one interviewee.
- **Grooming Successor**: An interviewee said that an important lesson that his mentor had taught him was that "you can't advance [in your career] without training a person to replace you" and that by following that advise, he has been presented with lots more opportunities than his peers. "Somebody's got to take over" the mentor's role and responsibilities in the organization – not just after retirement or after moving on to a different job, but also in the absence of the mentor. One interviewee who occupied a senior position in the organization had met with an accident and had to stay away from work for a few months during recovery. But since he had previously mentored someone, that person was able to fill the gap during his absence on the job.

Benefits to The Organization

Effective mentoring not only benefits the mentees and mentors involved in the relationship, but also the workforce as a whole. When this happens, the organization at large benefits as well. One of the early motivations of the Helix study was the concern that a significant number of senior systems engineers would soon be eligible for retirement and whether the organization would be able to effectively manage the gap that would be created. Mentoring is considered to be an effective way to help address this gap.

- **Gain Effective Knowledge Transfer**: When senior engineers retire, they typically take along with them many years' worth of valuable experience and expertise, and this is a major concern for any organization. Among various knowledge transfer mechanisms that organizations typically deploy, interviewees indicated that mentoring is very effective. In a couple of scenarios, organizations had budgeted time for documentation, but interviewees agreed that it was not a good decision and that mentoring would have been more effective. In one organization, interviewees felt that the organization was effectively handling the workforce situation (of retiring senior engineers) by including mentoring as part of the transition plan in the workforce.
- **Identify High-Potential Engineers**: Through the feedback from mentors, organizations can identify high-potential engineers who are being mentored. These young engineers could then be placed on a fast track or experience other organizational initiatives that would mature them faster into the next generation of experts and leaders.
- **Reduce Orientation Time**: When employees enter a new organization or department, irrespective of their educational and work background and experience, it takes some effort by the organization and by the individual before they can become productive and effective in their new roles. Most often, individuals spend a lot of time figuring out things by themselves, and in searching for the information and organizational procedures required to do their jobs. In these cases, effective mentoring can significantly reduce the time taken for such employees to get oriented to their jobs.
- **Fill Workforce Gaps**: When senior engineers retire, mid-level engineers most effectively fill the gap created and in many organizations there are not enough mid-level engineers. Through mentoring, such emerging workforce gaps can be filled proactively. In other situations, there exist some 'less sought after' jobs in an organization that are still important, e.g., test engineer. While talking about his job, one interviewee mentioned, "you would be surprised how many people don't want to do this job!" This could be due to a combination of organizational culture or misconception about what that job entails. Again, mentoring is an effective way to fill such workforce gaps that may not be filled easily otherwise.
- **Increase Employee Retention**: "Today, employees do not stay on with companies as long as they used to," said one interviewee. When younger employees leave, they also take along with them the learning and knowledge that they have acquired, and the organization stands to lose. When employees are recognized by the organization for their potential; when the organization and seniors invest time and effort on them; and when their work is deemed important, it significantly increases the loyalty of those employees towards their job and the organization. Mentoring helps increase such employee loyalty and thereby employee retention.
- **Improve Organization Culture**: Mentoring builds relationships and thereby naturally builds teams. It promotes a healthy environment where senior engineers are willing to share and teach, and junior engineers are recognized and encouraged. This creates a positive organizational culture that all employees are happy to be a part of. In one organization, "there a

number of people that are willing to help somebody – not 10% but 90% of the workforce; it is just part of the culture" said one employee.

13.2.4 Importance of Mentoring for Systems Engineers

Mentoring, in general, is helpful to any mentee in any organization – and not just for engineers. However, in the context of systems engineers and systems engineering, mentoring plays a particularly important role.

- **Systems Engineers Can be a Rare Commodity**: In some organizations, there are not enough systems engineers to perform the required systems engineering activities. In such cases, mentoring is an effective way to fill the pipeline of systems engineers, especially when there is likely to be a gap with the retirement of senior systems engineers. "There are not [as] many systems engineers as I thought," said one interviewee, "without mentoring there will be a loss".
- **Identifying and Recruiting Systems Engineering talent**: In many organizations recruitment directly into the systems engineering division or into a systems engineer's role does not happen; systems engineers tend to be brought in from other parts of the organization. In these cases, mentoring plays a crucial role where mentors help identify potential systems engineers and play the role of an advocate for systems engineering to encourage them to join systems engineering.
- **Support for New Systems Engineers**: As one participant said, "It isn't rare and it isn't uncommon to end up doing systems engineering if you were not a systems engineer before". In most organizations, this is a common way for recruiting systems engineers. So when non-systems engineers enter systems engineering, mentoring plays a key role in equipping them to be effective.
- **Changing Face of Systems Engineers**: Systems engineers used to be 'greybeards' who "floated up to the top and had all the experience". But today, depending on organizational policies and practices, engineers may become systems engineers without a lot of experiences. Mentoring becomes a critical initiative that could equip such systems engineers to be effective in their jobs.
- **Nature of Systems Engineering:** "As much as we like the young engineers to act as systems engineers, it's difficult for them to understand how our different taskings are integrated across," said one interviewee. "There's a big gap between young engineers and old experienced people with a lot of tribal knowledge" said another. Due to the nature of systems engineering, and particularly how it is performed in the organization, there is much to be learned hands-on that cannot be learned before entering the organization. Though education does help, it is not sufficient in most cases. One interviewee elaborated, "I had the advantage as a teenager, some of my mentors had been doing the work since the 1950's and they were about ready to retire. They were solving incredibly complex problems without computers, without high-end sensors. They had to really understand what they were doing and really have clever ways of solving the problem. So they really kind of passed on that skill set that you don't learn in college."

13.3 Analysis of Education

While the third force identified in *Atlas* is Education & Training, training is very specific to the organization, and there was insufficient and inconsistent information to perform any further analysis on training. Therefore, only the education of systems engineers, gathered primarily from their resumes, is included here. A comparison between junior systems and senior systems engineers provides additional insights into early career development of these two seniority levels. Data from INCOSE SEP applicants and analysis performed on their education background (Lipizzi et. al 2015) has also been used here.

13.3.1 Degrees Awarded

There are many types of degrees awarded to individuals in the interview sample. For Helix analysis, degrees were categorized by level: associate, bachelor's, master's, and doctorate degrees. For the purposes of this analysis, graduate certificates were not included.

The highest degree attained for systems engineers in the Helix interview data, divided by seniority, as well as applicants of the INCOSE SEP program, are listed in Table 6. Although there is very little overlap between the interview participants and the INCOSE SEP applicants, the distributions across degrees is fairly well aligned in both samples.

Table 6. Highest Degree Attained by Individuals

	Helix Interview Data				INCOSE SEP Data
Degree Level	**Junior**	**Mid-level**	**Senior**	**All**	
Associate's	0%	0%	0%	0%	<1%
Bachelor's	44%	23%	32%	33%	30%
Master's	56%	73%	56%	58%	61%
Doctorate	0%	5%	12%	9%	8%

The following observations can be made from Table 6:

- All individuals in the interview sample have at least a bachelor's degree; very few of the INCOSE SEP applicants have only an associate's degree.
- The majority of the interviewees have a master's degree (58%), which is close to the fraction of INCOSE SEP applicants (61%). In general, systems engineers are a highly educated group.
- Mid-level systems engineers in the interview sample have a much higher percentage of master's degree attainment than either junior or senior systems engineers. It is possible that this is reflection of the distribution of the sample population, by seniority. Another plausible explanation is that many junior systems engineers haven't been practicing professionals long enough to seek a master's degree and that many senior systems engineers grew up in a time when advanced degrees, particularly in systems engineering, were not as important for career advancement as they are now.
- Among interviewees, there is a higher percentage of senior systems engineers with PhDs than mid-level systems engineers; no junior systems engineers in the sample have a doctorate degree.

13.3.2 Bachelor's Degrees

Bachelor's degrees generally provide the foundation on which a systems engineer's career is built. Figure 26 shows the most common majors in bachelor's degrees among Helix interviewees and INCOSE SEP applicants. There is a wide variety of degree titles, especially in the INCOSE SEP data that includes non-US applicants. In the interview sample, there were 81 total degree titles; in the applicant sample, there were 453 unique degree titles for bachelor's degrees and 524 for master's degrees. All these titles were normalized into the major categories used in Figure 26 (Lipizzi et. al 2015).

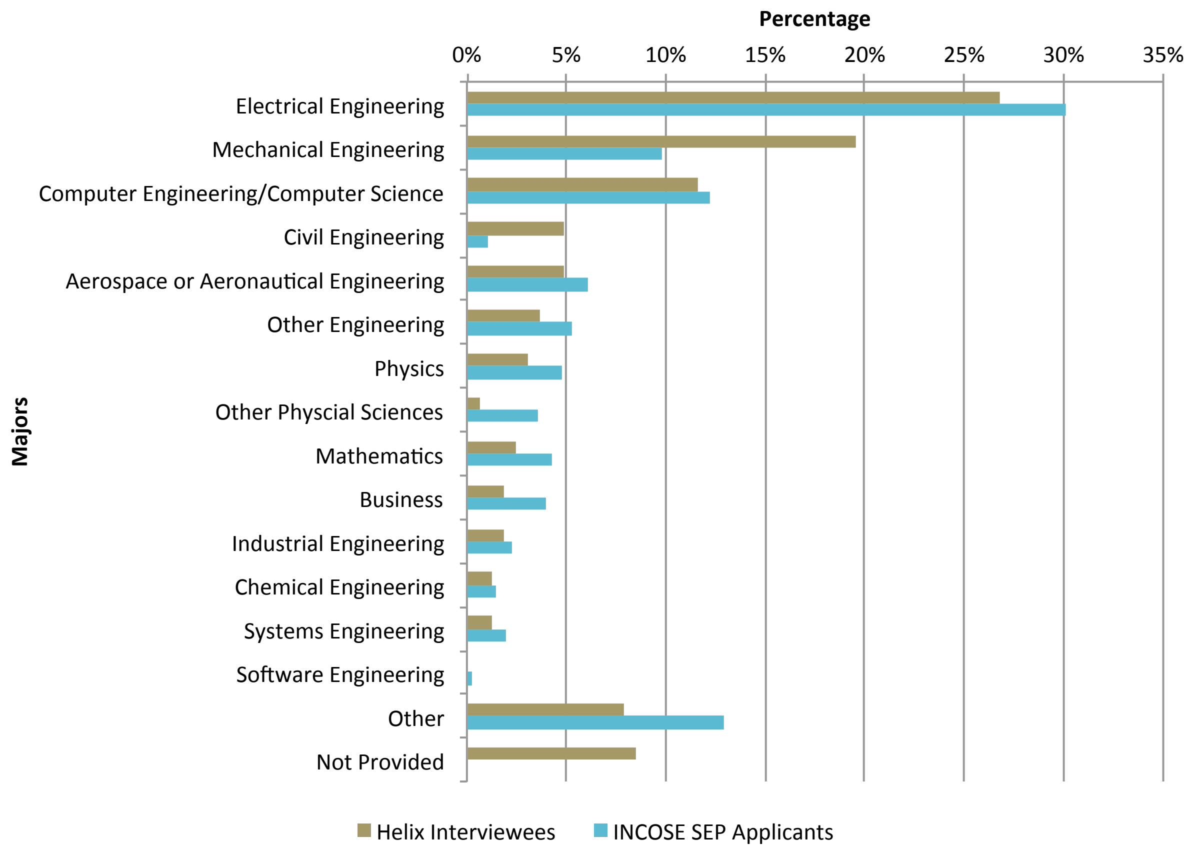


Figure 26. Bachelor's Degree Majors for Helix Interviewees and INCOSE SEP Applicants

The following observations can be made from Figure 26:

Though the order and percentages differ slightly between Helix interviewees and INCOSE SEP applicants, the overall pattern in popularity of these majors is generally aligned in both samples.

- Among interviewees, over 75% have bachelor's degrees in engineering fields; a small number were educated in the physical sciences (4%) or mathematics (2%).
- Bachelor's degrees in systems engineering (and related degrees) are rare, at just over 1%.
- The majors represented under "other" were not technical fields (e.g., French, music, quality assurance, and leadership). A few individuals had more than one bachelor's degree, but this was rare (2%) and typically the second degree was not technical (e.g., music and French).

- In both data samples, the most common bachelor's major is electrical engineering. In the 1970's, electrical engineering was a more common major in the US than mechanical; this trend has reversed over time (NCES 2010).

Bachelor's degrees were attained at the start of or within the first 3 years of all systems engineers' careers in the interview sample. Table 7 shows a comparison of bachelor's degree majors for junior versus senior systems engineers.

Table 7. Comparison of Bachelor's Degree Majors of Junior and Senior Systems Engineers

Bachelor's Degree Majors	Junior	Senior
Electrical Engineering	26%	34%
Mechanical Engineering	26%	22%
Civil Engineering	15%	2%
Computer Engineering/Science	15%	9%
Aeronautical/Aerospace Engineering	7%	6%
Systems Engineering	0%	1%
Software Engineering	0%	0%
Engineering, other	7%	1%
Physics	0%	6%
Other Physical Sciences	0%	1%
Mathematics	0%	3%
Business	4%	1%
Other	0.%	13%

The following observations can be made from Table 7:

- When many senior systems engineers were working on their bachelor's degrees, electrical engineering was a more popular major.
- Civil engineering and computer engineering/science are more common in the junior systems engineering population than in the senior.
- None of the junior systems engineers in the sample have undergraduate degrees in physics, other physical sciences, or mathematics; these are present, though uncommon, in the senior systems engineer population. Among interviewees, individuals with degrees in these areas typically began their careers conducting analysis, conducting tests, working on requirements gathering, or in planning. These individuals did not conduct detailed analysis or larger-scale verification and validation efforts.

In the interview sample, three paths were observed:

1. Individuals started in a non-technical field but later sought a bachelor's degree in a technical field;

2. Individuals had one or more minors in technical fields, and utilized those for their career growth;
3. Individuals came to engineering based on a circuitous route and first gained engineering experience before pursuing formal education in these areas.

13.3.3 Master's and Ph.D. Degrees

Over 50% of the Helix interviewees have a master's degree, as well as almost 2/3 of the INCOSE SEP applicants. Of the Helix interviewees with master's degrees, 12% earned more than one master's degree. These percentages are considerably higher than in the general US population, in which around a 1/3 of individuals have a bachelor's degree and around 1/10 have graduate level education (US Census Bureau 2014). This indicates that systems engineers, as a group, are much more highly educated than the general population.

The majors for master's degrees for both the Helix interviewees and the INCOSE SEP applicants are shown in Figure 27:

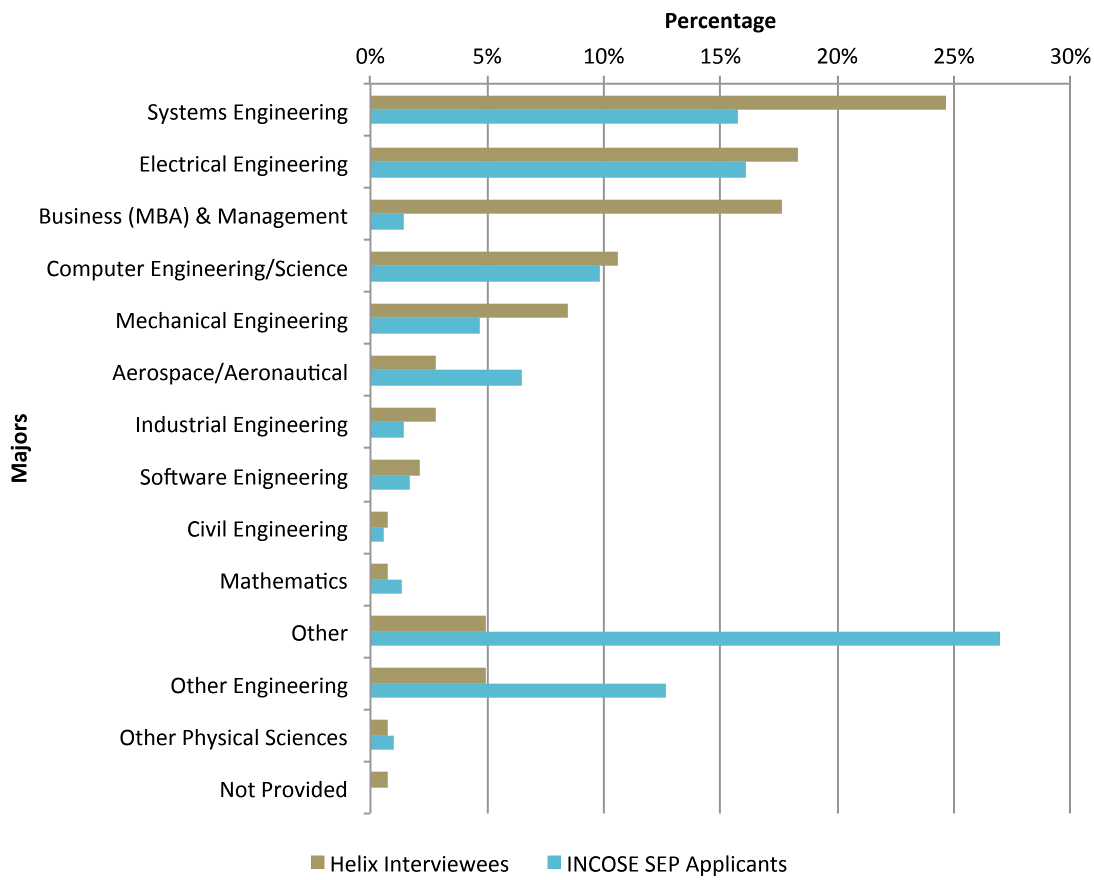


Figure 27. Master's Degree Majors for The Helix Interview Data and INCOSE SEP Data

The following observations can be made from Figure 27:

- Almost 3/4 of the Helix interviewees and over 2/3 of the INCOSE SEP applicants have a master's degree in an engineering field.

- Both samples have very few individuals (less than 1% in each) with master's degrees in the physical sciences.
- The most common master's major among interviewees and one of the most common in the INCOSE data was systems engineering. A quarter (25%) of the Helix interviewees and 16% of the INCOSE SEP applicants have a master's degree in systems engineering.
- The high percentage of 'Other' in INCOSE data indicates that the majors, especially from non-US universities, did not directly fall under any other category.

Table 8 shows a comparison of master's degree majors for junior versus senior systems engineers in the interview sample.

Table 8. Comparison of Master's and PhD Degree Majors of Junior and Senior Systems Engineers

Degree Majors	Master's		Ph.D.
	Junior	Senior	(Senior)
Electrical Engineering	10%	21%	17%
Systems Engineering	50%	20%	33%
Computer Engineering/Science	5%	11%	0%
Mechanical Engineering	5%	10%	8%
Aeronautical/Aerospace Engineering	5%	3%	0%
Software Engineering	5%	1%	0%
Civil Engineering	5%	0%	0%
Engineering, other	0%	9%	8%
Physics	0%	1%	8%
Physical Science, other	0%	1%	8%
Mathematics	0%	1%	0%
Management	0%	18%	8%
Other	5%	4%	8%

The following observations can be made from Table 8:

- As indicated in Table 6, no junior systems engineers had a Ph.D. degree in the Helix interview data.
- In both master's and PhD degrees, systems engineering and electrical engineering are the most common fields of study.
- While 18% of master's degrees attained were in business or management fields in the interview set, only 6% of the INCOSE SEP applicants have business or management-related master's

degrees. Among INCOSE SEP applicants, 41% of individuals with a master's of business degree also have a technical degree.

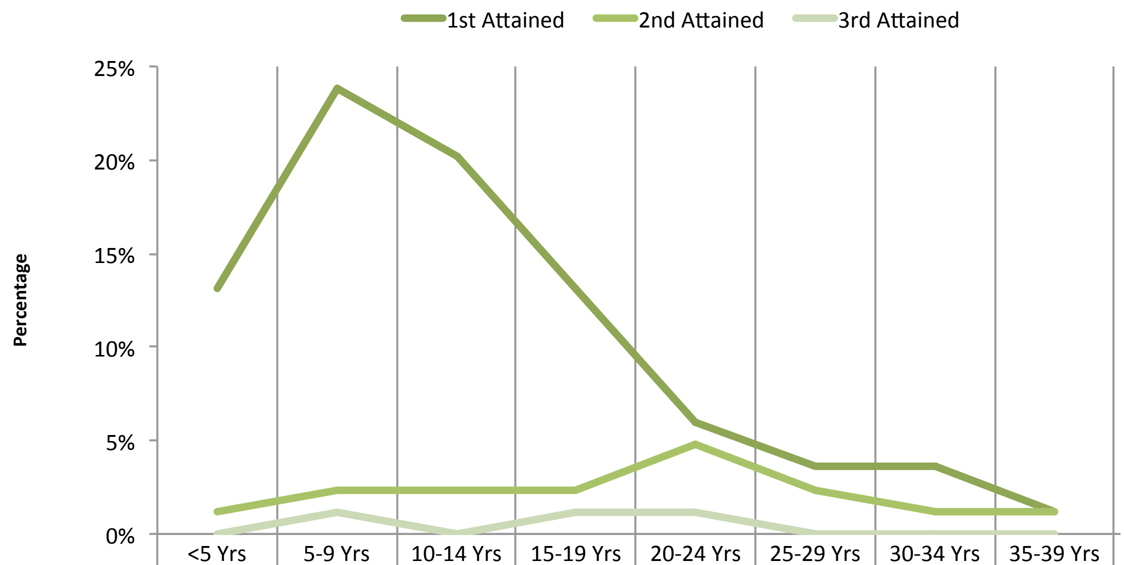
- Among interviewees, most PhD majors were unique with two exceptions: systems engineering (33%) and electrical engineering (17%).

Research by Lasfer and Pyster (2013) shows very strong growth in systems engineering master's graduates from 2001-2010. The increased popularity and availability of systems engineering programs in the 2000's then, is common throughout the systems engineering community in the US. Graduate education in systems engineering has grown significantly in the last 15 years, and senior systems engineers have proven less likely to pursue this degree. Growth of academic programs generally occurs in response to industry demand. Almost all interviewees who were asked about the growth of systems engineering in their organizations explained that it has only been in the last 15-20 years that the field of systems engineering has come to be clearly defined as a separate discipline and is recognized and pursued by participating organizations. Industry interviewees frequently cited increased governmental focus on systems engineering as the primary driver for their organization's focus on the discipline. Of course, systems engineering was still performed during the last century, but as several interviewees stated, "we didn't call it that." As the recognized desire for systems engineering has increased, it follows that more educational programs would be started and more people would graduate from these programs. All senior participants who were asked why they chose not to pursue a master's degree in systems engineering stated that they felt that it was more appropriate for people earlier in their careers, and that their extensive experiences provided more breadth and depth of systems engineering knowledge than would be attained through graduate study. In addition, many of the senior systems engineers without a master's degree in systems engineering (about 80%) still had at least one master's degree in another field and felt that they did not require a second master's degree.

13.3.4 Timing of Master's Degree Attainment

The timing of when a master's degree is attained during a systems engineers career offers insights into the motivation and relevance of obtaining the master's degree.

Master's degrees were most commonly attained within the first half of a senior system's engineer's career. The distribution of the length of time in career before attainment of master's degrees for senior systems engineers can be seen in Figure 28.



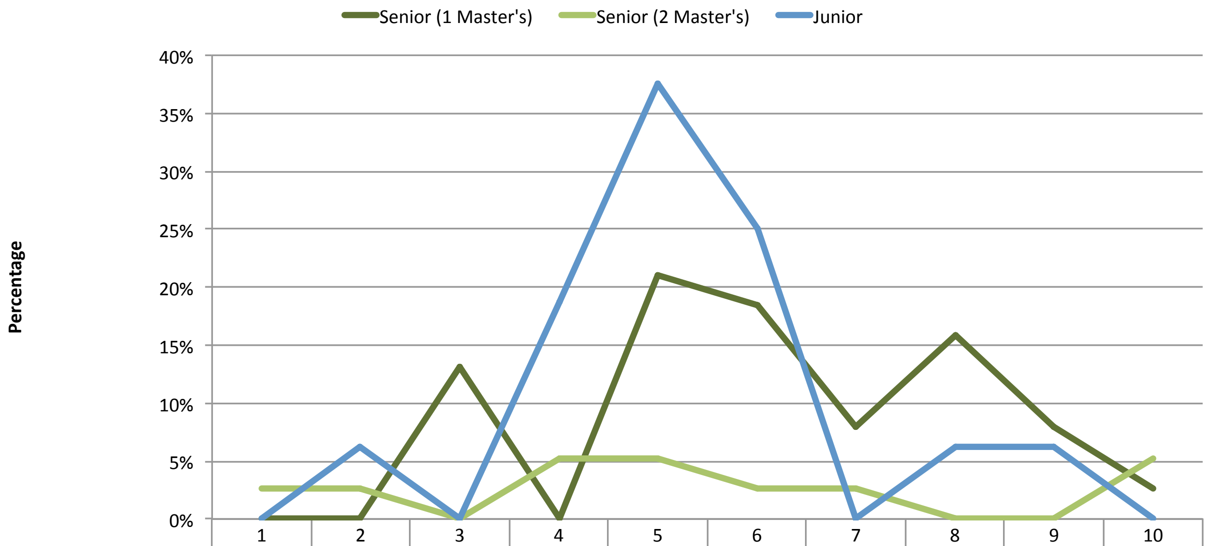
	<5 Yrs	5-9 Yrs	10-14 Yrs	15-19 Yrs	20-24 Yrs	25-29 Yrs	30-34 Yrs	35-39 Yrs
1st Attained	13.10%	23.81%	20.24%	13.10%	5.95%	3.57%	3.57%	1.19%
2nd Attained	1.19%	2.38%	2.38%	2.38%	4.76%	2.38%	1.19%	1.19%
3rd Attained	0.00%	1.19%	0.00%	1.19%	1.19%	0.00%	0.00%	0.00%

Figure 28. Timing of Master's Degree Attainment for Senior Systems Engineers

The following observations can be made from Figure 28:

- Most senior systems engineers tend to receive a master's degree within the first 15 years of their careers (57%).
- For about 3/4 of those who did attain a second master's, it happened within 15 years of attainment of the first master's degree.
- For those senior systems engineers with a second master's degree, the most common majors were systems engineering (31%) and business or management (31%).
- There are no discernable patterns for the 3% of senior systems engineers with three master's degrees.

A comparison of the first ten years of the careers of senior systems engineers and the careers of today's junior systems engineers in terms of master's degree attainment is illustrated in Figure 29.



	1	2	3	4	5	6	7	8	9	10
Senior (1 Master's)	0.00%	0.00%	13.16%	0.00%	21.05%	18.42%	7.89%	15.79%	7.89%	2.63%
Senior (2 Master's)	2.63%	2.63%	0.00%	5.26%	5.26%	2.63%	2.63%	0.00%	0.00%	5.26%
Junior	0.00%	6.25%	0.00%	18.75%	37.50%	25.00%	0.00%	6.25%	6.25%	0.00%

Figure 29. Comparison of Master's Degree Attainment for Junior and Senior Systems Engineers in The First Ten Years of Their Careers

Almost 2/3 of junior systems engineers who have pursued a graduate degree completed their degree within the first 5 years of their careers (65%); a little more than a 1/3 completed their master's degree 5 years or more into their careers, although none more than 8 years into their careers (36%). Of the systems engineers in the sample who have not completed a master's degree program, two individuals were pursuing a degree when interviewed; almost all of the others indicated during their interviews that they plan to pursue a master's degree in the future.

As discussed earlier, there is a steady growth trend in systems engineering graduate education in the US (Lasfer and Pyster 2013). As the availability of systems engineering graduate education increases, it is reasonable to expect that an increasing number of junior systems engineers would seek a master's in the field. This cannot, however, account for over half of all master's education among junior systems engineers being in systems engineering. Junior systems engineers explained that they sought graduate degrees in systems engineering for several reasons:

- **To Learn Other Ways of Doing Things.** Junior systems engineers often have worked in only one or two organizations. Where they see limitations in the way systems engineering is done in these organizations, they often feel powerless to make changes. By studying systems engineering academically, however, they believe they can better understand alternatives and have a better chance of making an impact on their organization.
- **Broadening of Knowledge.** Junior systems engineers almost unanimously expressed a desire to see different parts of the lifecycle, experience different technologies, understand new techniques in the field, etc. However, these experiences are not always possible in their current organizations or may not be available as soon as the junior systems engineers desire. By obtaining a master's degree in systems engineering, junior systems engineers can at least gain

more knowledge on the aspects of systems engineering they have not yet experienced, understand lifecycles from a more holistic perspective, understand multiple processes, and gain exposure to different types of tools. Junior systems engineers who have graduate degrees in systems engineering also expressed concern that their knowledge and skills will atrophy if they are not able to practice them.

- **General Career Growth.** Junior systems engineers generally expressed a desire for growth in their careers, and believed that earning a master's degree in systems engineering would help with this in several ways:
  - Simply obtaining graduate level education in some cases made them eligible for promotions or other incentives that they otherwise would not have had.
  - Systems engineers are often in the position of having to influence engineering decisions, without having authority over the engineers doing the work or making the decisions. Several junior systems engineers stated that having a master's degree gave them at least some level of "street credit".

14 ANALYSIS OF CHARACTERISTICS

Characteristics of the individual systems engineer and of the organization play a key role in determining the impact of the various forces that *Atlas* has identified. Helix interviews revealed the characteristics that most enable improving one's proficiencies.

14.1 PERSONAL CHARACTERISTICS

The proficiency framework provides details on various knowledge, skills, abilities, behaviors, and cognitions that systems engineers need in order to be effective. In addition, there are certain characteristics that systems engineers possess that influence the impact of value delivery; they also influence the impact of the forces on the effectiveness of the systems engineer. For example, two individuals with similar educational backgrounds and experiences undergoing the same training program may accrue different levels of benefits.

These characteristics influence the proficiency of the systems engineer and the impact of the forces on changes in those proficiencies. The characteristics are also different from the proficiencies identified in *Atlas* because the characteristics are focused on the qualities of an individual versus the skills or abilities of that individual. This distinction was sometimes difficult for interviewees to grasp, particularly when they are compared with *Systems Engineering Mindset* categories such as *Big-Picture Thinking* or *Paradoxical Mindset*. The differentiation is that "personal characteristics" are traits of the individual that may *enable* the development of these proficiencies, but they do not in and of themselves ensure that an individual has a certain level of proficiency.

The two proficiency categories that most interact with personal characteristics are *Big-Picture Thinking* and *Paradoxical Mindset.* For example, one pairing in *Paradoxical Mindset* is "courageous and humble". Two characteristics commonly cited were "courage" and "humility". These clearly support the category of *Paradoxical Mindset*. However, neither is in itself a guarantee of proficiency. Instead, *Paradoxical Mindset* indicates that an individual both possesses these characteristics and also can make a judgment based on the current situation as to which characteristic should dominate. Finally, while the proficiencies are specific for systems engineers, the characteristics described here are not specific to any field, though they have been cited as critically important for systems engineers. These subtleties will be further explored in future versions of *Atlas*.

The primary personal characteristics are identified below. Some characteristics are combined into larger, related groupings for ease of understanding.

- **Self-Awareness:** Systems engineers need to be able to self-reflect and become aware of their strengths and weaknesses; what they know and don't know; and where they are right and where they are wrong. Of the feedback Helix received on critical characteristics, 11% focused specifically on the need for self-awareness. An increased awareness of oneself is only the first step; to acknowledge gaps or areas for improvement and to correct them requires humility and modesty as well. Of the individuals who felt self-awareness was critically important for systems engineers, 14% indicated that humility was a critical supporting characteristic. Such self-awareness also brings clarity to a systems engineer's mind as to where they can rely on their own knowledge and where they need to seek the expertise and experience of others. Another interviewee said, "The best systems engineers I work around are people that don't think they know everything." Additionally, 21% of the systems engineers who focused on self-awareness explained that courage was also critical; it takes courage to admit your weaknesses to yourself and others; it takes courage to seek opportunities to improve in these areas. Self-awareness was described as a critically important characteristic for the development of *Big-Picture Thinking* (21%) and *Paradoxical Mindset* (21%).

- **Ambition and Internal Motivation:** Systems engineers tend to be very ambitious in terms of their career goals as well as the nature of the systems they wish to engineer. Many systems engineers who participated in Helix interviews expressed a desire to eventually become a 'Chief Systems Engineer' or play another senior role, and to also work on increasingly complex projects. Such high ambitions make systems engineers very strongly motivated internally. Even in challenging situations, they are able to generate energy and motivation within themselves, without relying on an external source, which was highlighted in 8% of the feedback on characteristics. They tend to approach any problem with a 'can-do' attitude. A fifth of the individuals who discussed internal motivation stated that it also tends to be correlated with self-awareness; as individuals are motivated to grow and improve, they have to be honest with themselves about their own capabilities in order to determine a best path forward. Ambition and internal motivation were typically described as critical characteristics for the development of *Big Picture Thinking* (62%) and *Paradoxical Mindset* (15%).
- **Inquisitive:** Systems engineers, as a group, tend to be very inquisitive, constantly asking "why" questions and trying to understand how a system, project, or team really works. This is a reflection of the naturally curious nature of many systems engineers, and 10% of the excerpts on characteristics focused around this curious and inquisitive aspect. As one interviewee stated, "I think most engineers who really like engineering are just curious and they want to understand how things work and how things go together and then be challenged to work on and solve different problems. About a third (31%) of individuals who discussed the importance for systems engineers to be inquisitive explained that courage was an important supporting characteristic; systems engineers who are too timid may not ask the necessary questions and many indicated that inquisitiveness is critical to the development of proficiency in *Big-Picture Thinking* (40%).
- **Lifelong Learning:** Systems engineers need to stay current with recent developments in technologies, tools, and processes. To maintain technical relevance, they must constantly improve their understanding of the system's domain and related disciplines. This means that systems engineers need to be students all their lives, constantly learning and increasing their knowledge, irrespective of their seniority or position in the organization. This was cited as a critical characteristic by 6% of the sample. Related to the ability to learn is also the ability to teach and share knowledge with others. It is common for systems engineers to play the role of a teacher or mentor to members of their team. Lifelong learning was commonly correlated with internal motivation (25%); the desire for growth and change is addressed by continual learning. A quarter of the excerpts on lifelong learning indicated that it was a critical characteristic for the development of *Big-Picture Thinking*.
- **Confidence, Persistence and Focus:** Systems engineers must be confident in their own abilities in order to interact effectively with organizational top management, with subject matter experts who are technically sound, with strong personalities who are highly opinionated, and with end customers whose requirements are to be satisfactorily met for the system to be successful. Systems engineers are not known to be shy, and they do not 'give-up' easily. They remain persistent to make things progress towards the end goal and vision for system success, which is always in their focus; and they do not get distracted easily. (6%) It requires some courage to be confident in one's abilities when dealing with multiple stakeholders and carry one's belief in the correct approach or decisions forward (11%). These characteristics were seen as critically

important for the development of *Big-Picture Thinking* (33%), *Paradoxical Mindset* (7%), and effective *Communication (*33%).

- **Professionalism and Respect:** Systems engineers deal with a wide variety of people across the technical, programmatic, and business aspects of their work and often must lead through influence rather than direct authority. It is critical, therefore, that they are professional in their conduct, mannerisms, and behaviors and that they maintain a good work ethic. They treat others with respect, and acknowledge their strengths, contributions, and the value they bring to the team and the organization. They are patient when they need to be, and tend to 'tolerate' difficult people well. In order to achieve this, they must possess a certain level of humility (58%), focus on and respect for the variety of social backgrounds and personalities on their teams (25%), sense of their own accountability to the team (8%), and maintain ethical behaviors (8%). Interviewees viewed these attributes as critical to developing several proficiencies: *Building a Social Network* (50%), *Paradoxical Mindset* (13%), *Big-Picture Thinking* (9%), *Communication* (9%), and *Flexible Comfort Zone* (9%).

- **Creativity**: "Systems engineering is a unique combination [of] left brain – right brain working together," said one interviewee; others also indicated that there was an artistic side to systems engineering. In terms of how creativity could be fostered, most interviewees elaborated not on their professional experiences but focused more on their hobbies, interests, and life in general outside the office, and the influence of all those on their professional life as a systems engineer. In many cases, participants talked about developing the proficiencies in the *Systems Engineering Mindset* category very early on in life, and through personal interests. Among the systems engineers who participated in Helix interviews were musicians, avid readers, poets, painters, authors, puzzle-lovers, dancers, and gardeners. A quarter of individuals who discussed creativity explained that they loved puzzles from an early age and internalized a critical lesson from their work on puzzles: that there *is* a solution to any challenge – it may not be obvious, but it exists somewhere to be discovered. Individuals who discussed creativity indicated that it was critically important to the development of proficiency in *Big-Picture Thinking* (50%) and *Paradoxical Mindset* (50%).

The personal enabling characteristics discussed above play a critical role in the development of effective systems engineers. Some interviewees who had been mentors or supervisors of systems engineers stated that these characteristics often serve as indicators for identifying potentially effective systems engineers. Experiences and mentoring appear to have the strongest influence on the development of these characteristics. None of the systems engineers who provided detail on characteristics discussed how education or training supported them.

As noted above, interviewees commonly cited two proficiencies as being well supported by these characteristics: *Big-Picture Thinking* and *Paradoxical Mindset*. Other proficiencies were discussed, but with 24% of the total excerpts on characteristics being correlated to *Big-Picture Thinking* and 11% correlated to *Paradoxical Mindset*, these were the most commonly linked to characteristics. The characteristics that most strongly supported *Big-Picture Thinking* were inquisitiveness (25%) and internal motivation (13%), though 14 other characteristics also were described as supporting development of proficiency in this area. For *Paradoxical Mindset*, self awareness had the strongest correlation (20%) and creativity, curiosity, and humility were each correlated with development of proficiency (13% for each respectively); an additional 6 characteristics were also described as supporting development in this area.

The current sample of 131 excerpts on characteristics is useful, but the Helix team will work to collect more data on the explicit relationships between the characteristics themselves and how they support development of the proficiencies – either directly or through the *Atlas* forces. This will further refine and improve the discussion of personal characteristics for future versions of Atlas.

15 ANALYSIS OF INITIATIVES

The various initiatives that an individual or an organization may generate are contextual and subjective. The organizational initiative that was discussed by systems engineers across most organizations was mentoring. Systems engineers who had experienced some level of mentoring in their careers, either in the current or in one of their former organizations, mentioned the significant impact it had in the development of their career. Some critical factors that need to be addressed to increase the success potential of a mentoring initiative are described in this section.

15.1 CRITICAL FACTORS FOR SUCCESS WITH MENTORING

Though mentoring is considered to be an effective solution to address the gap that could be created by an aging retiring workforce, just the existence of a mentoring arrangement, either formal or informal, by itself does not guarantee success. However, there are factors that significantly influence the success or failure of any mentoring arrangement, and interviewees provided a number of anecdotes and personal experiences to elaborate on this. Recognizing and addressing these factors by the organization and the individuals involved could prevent failure and could vastly increase the chances of success with a mentoring arrangement.

- **Mentoring Has Its Limitations**: Mentoring does not always work in all organizations, for all employees; mentoring does not work in isolation, but in conjunction with other organizational initiatives to support its employees, such as training and education; and mentoring cannot be solely relied on for knowledge capture from a retiring senior engineer. Even with respect to mentees who stand to benefit the most in a mentoring arrangement, one interviewee stated, “I do not see different traits among those formally mentored, informally mentored, and not mentored at all.” While there are many other cases that would prove this statement wrong, it only shows that mentoring is not a universal solution. One interviewee stated “I’ve seen great systems people that have no formal mentoring”. While it is possible that any mentoring could have been implicit and not visible outside, it shows that while mentoring is highly desired, it may not be essential for everyone. Another interviewee supported this view when he said “I’m proof that [mentoring] is not essential; it just made it more uncomfortable for me.”
- **Right Choice, Right Pairing**: Ineffective mentors exist, and just the fact that someone is a true expert with many years of experience would not automatically make them a great mentor. In some mentors ‘communication’ could be a factor, but ‘willingness’ could also be a factor. As one interviewee elaborated, “some are good with sharing their knowledge, and there are people who don’t want to share any of their knowledge”. Similarly, not everyone benefits from being a mentee; some are more comfortable learning things on their own than from a mentor. Finally, it is most important to pair the right mentor with the right mentee – alignment between them is important; “[mentoring] is a two way street” said one interviewee, and it can become a “life long relationship”.
- **Balance between Formal and Informal Mentoring**: While most interviewees had a personal preference for informal mentoring, everyone agreed that a bit of formality does help. Therefore, establishing the right balance between formal and informal mentoring by the organization is critical. As discussed in Section 13.2.2, there are some aspects of mentoring that benefit from a formal arrangement – such as establishing goals and objectives, and keeping track of mentoring arrangements. But for aspects such as deciding the right mentor-mentee pair; and for driving the frequency and nature of the interactions, it is advantageous to let those be informal.

- **Mentor Training**: Mentors may possess the experience and expertise that mentees stand to benefit from, but some guidance on establishing and sustaining a mentoring relationship would help – it does not come naturally to all mentors. Providing some guidance on how to establish goals and objectives for mentoring, and on how to balance teaching and guiding (for self learning by mentees) would be beneficial to mentors. In one organization, interviewees mentioned that there was a mentoring manual, but it was very dated, and that currently mentoring happens in a more ad-hoc manner.
- **Make Mentoring Visible**: If any mentoring program is officially established or encouraged by an organization, it must also take the effort to make it known to all its employees. In some organizations, the interviewees were not aware if their organization had a mentoring program or not. In some cases, top management initiated a mentoring program that failed to percolate through the organization to reach the potential mentors and mentees. One interviewee said, "I didn't even know we had [a mentoring initiative] until someone gave me a mentee."
- **Mentoring Needs Time**: Benefits of mentoring cannot be reaped instantaneously – in some cases, it is only after a number of years that mentees benefit from the mentoring that they had received early on in their careers. Similarly, mentoring cannot be a last minute activity that a retiring senior engineer is expected to do in the last few months or weeks of employment – any mentoring done at that time is not likely to be very effective. With many other activities taking priority before retirement, there is usually not enough time mentoring. Mentoring cannot be rushed, even from the perspective of the mentee who cannot be expected to "think of all questions [to the mentor] today."
- **Load on Mentor**: Organizations must always be aware of the load that mentoring places on the mentor – they cannot be expected to do everything that they are responsible for and also do mentoring. At the same time, mentoring cannot be a fill-in activity where a mentor is told, "you are not busy this month – so go mentor this person."
- **Back up a Mentoring Program**: In one organization, a formal mentoring program was rolled out where everyone would have a mentor and a mentee. It was formal; but "it wasn't backed by a lot of horse power", as noted by an interviewee. The organization needs to back up a mentoring program with the required budget and time for the mentor and mentee to engage in a relationship – it is dangerous to establish a mentoring program just to claim that one exists. Breaking a mentor-mentee relationship can also be harmful – such break ups could happen for a number of reasons, but if it is something that an organization could prevent, it should.
- **Terminating a Mentoring Arrangement**: Even while a mentoring initiative continues to remain active, there are situations that may warrant the termination of a mentoring arrangement. When the mentee chooses to leave the organization, it could be a loss to the organization if the mentee had received mentoring from soon-to-be-retiring senior mentor. Similarly, when a senior mentor chooses to leave abruptly, it could affect the knowledge capture that may have been in process through the mentoring arrangement. However in either of these cases, the organization may not be able to do much. But when there is a likelihood of an existing mentoring arrangement to be disrupted due to promotions or internal re-organization of either the mentee or the mentor, the organization must take care to provide sufficient time to the mentor and mentee to terminate the mentoring arrangement in a cordial manner, especially if the mentoring arrangement was successful and valuable to the mentor and the mentee.

PART 4

CAREER PATH ANALYSIS AND INITIAL *ATLAS* DEPLOYMENT FOR CAREER AND WORKFORCE DEVELOPMENT

The objective of the Helix project, beyond developing *Atlas*, is to enable individuals and organizations to use Atlas for personal development of effective systems engineers at the individual level and for developing an effective systems engineering workforce at a team or organizational level.

While Part 2 presented the elements of *Atlas* and Part 3 elaborated on the building of *Atlas* along with related insights, Part 4 presents initial thoughts on *Atlas* deployment in the following sections:

- Section 16 examines the careers of Chief Systems Engineers, with an aim to extract recommendations that would help young systems engineers to develop their careers towards becoming Chief Systems Engineer in future.
- Section 17 presents the career path of an individual Chief Systems Engineers, to illustrate the value of mapping an entire career onto the career path visualization framework proposed by *Atlas*.
- Section 18 offers a glimpse into some initial efforts carried out by Helix in 2015 towards assessment of the proficiencies of individual systems engineers, and the potential benefits individuals and organizations can accrue from similar efforts.

16 EXAMINING THE CAREERS OF CHIEF SYSTEMS ENGINEERS

The description of a career path is only useful to the extent that it provides valuable insights about how individual systems engineers can grow, mature, and develop their own careers. But what are the paths that lead to success? From the Helix interview data, a Chief Systems Engineer (CSE) is one of the most senior technical positions that a systems engineer can achieve. Individuals who became CSEs were able to do so because they had proven themselves to be effective throughout their careers, and had continually demonstrated the ability to take on increasing responsibilities. Hence, Helix considers the careers of CSEs worthy of further examination, since it can provide valuable insights to systems engineers early in their career to be develop into CSEs in future.

Helix identified 22 individuals in the interview sample who currently hold or have held the CSE position, for further analysis. Though many aspects of education and experiences were explored, a select few which provided particularly strong impacts on proficiency are discussed here: overall educational background; experiences across systems engineering lifecycle phases; and experiences across systems engineering roles.

In addition, there was a wealth of information available from the INCOSE SEP applications, especially on individuals applying for Expert Systems Engineering Professional (ESEP) certification. That information from INCOSE SEP data was also analyzed by Helix.

16.1 OVERALL EDUCATIONAL BACKGROUND

Each CSE in the sample had a bachelor's degree; for 23% of interviewees, this was the highest degree attained. Around two-thirds of CSEs (64%) held at least one master's degree and 9% held a PhD. The most common majors for bachelor's degrees and master's degrees are shown in Table 6.

Table 9. Bachelor's and Master's Degree Majors of CSEs

Degree Majors	Bachelor's	Master's
Electrical Engineering	45%	21%
Mechanical Engineering	18%	4%
Civil Engineering	5%	0%
Computer Engineering/Science	5%	8%
Aero/Astro Engineering	0%	4%
Systems Engineering	5%	8%
industrial Engineering	9%	0%
Physics	5%	0%
Mathematics	5%	4%
Business	5%	38%
Other	0%	13%

The following observations can be made from Table 6:

- 85% of CSEs have bachelor's education in engineering fields; a small number were educated in the physical sciences, mathematics, or business (<5% of each).
- Bachelor's education in systems engineering was also seen in less than 5% of CSEs. It was very common in the overall Helix sample for systems engineers to start out in specialty engineering fields, and the educational backgrounds of CSEs indicate that this was true for them as well.
- In general, engineering bachelor's education prepared CSEs with sufficient proficiency in *Math/Science/General Engineering* to perform detailed design work, do detailed analysis, or support test and evaluation.
- Of the nearly 2/3 of CSEs with master's degrees, 43% earned more than one such degree.
- Only 8% of the CSEs have a master's degree in systems engineering; this is considerably lower than the overall rate of systems engineering graduate degrees in the total Helix sample (26%).
- Most CSEs indicated that they believed their experiences were sufficient and they did not believe that they would benefit enough to warrant the effort required to earn a master's degree in systems engineering.
- About a 1/3 of CSE's master's degrees (38%) were in engineering fields outside of systems engineering; this is lower than what is seen among other senior systems engineers in the sample (50%).
- The most common master's field among CSEs was related to business (38%); generally, these were MBA degrees, though occasionally they were master's of science degrees related to more technical fields such as technology management. Less than half of these (44%) were second master's degrees. The CSEs with these degrees explained that they felt they had sufficient technical understanding but needed to learn more about business, management, finance, and other disciplines that support understanding business processes.
- Doctoral degrees were less common among CSEs (9%) than in the other senior systems engineers in the sample (12%). The most common PhD concentration in the overall sample was systems engineering, but there is no single common field of doctoral study among CSEs; electrical engineering, geotechnical engineering, and atmospheric sciences have equal representation. Doctoral studies were not required for advancement for any of the CSEs. Instead, those with PhDs indicated their continued desire to learn and grow and improve their understanding of specific disciplines was their motivation.

16.2 Experiences across Systems Engineering Lifecycle Phases

All of the CSEs in the sample have experiences across either four or five lifecycle phases, but none of the CSEs have experienced all six of the lifecycle phases. Figure 30 provides insight into the order in which CSEs experienced the systems lifecycle.

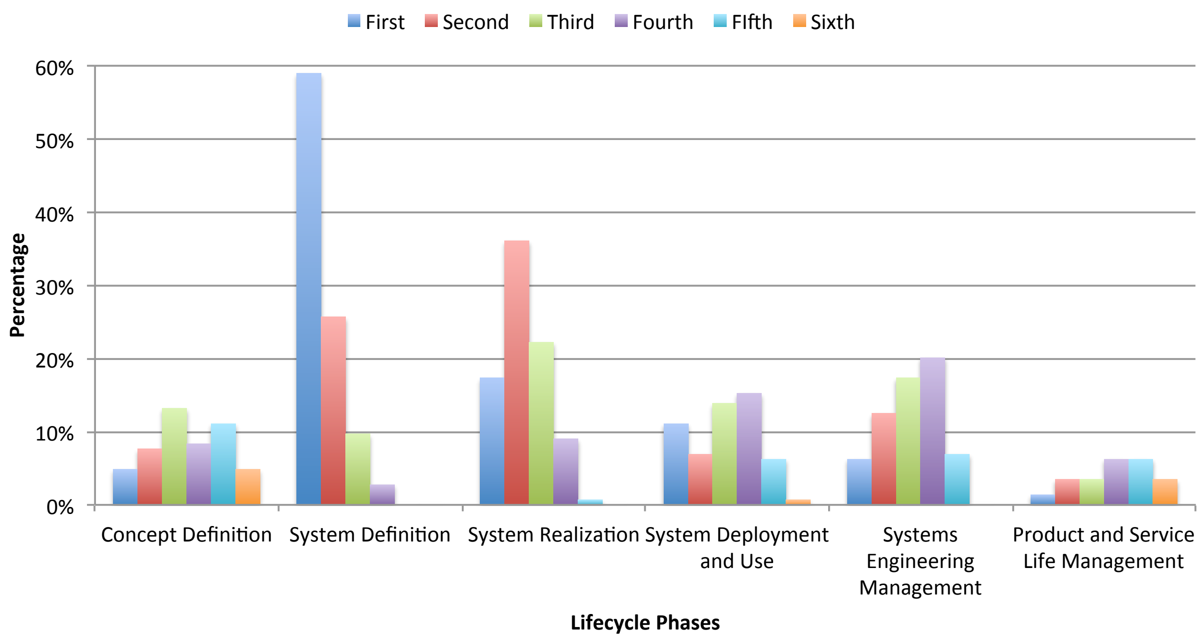


Figure 30. Order of Exposure to Lifecycle Phases Experienced by CSEs

There were a few clear patterns in how CSEs moved through the systems lifecycle process activities:

- All CSEs have experienced *System Definition*, *System Realization*, and *Systems Engineering Management*. This is a higher rate than seen in the overall Helix population (98%, 86%, and 64%), respectively.
- The most common point of entry for CSEs was *System Definition*; it was either the first or second aspect of the lifecycle experienced by 82% of CSEs. The most common pathway for entry into systems related work was through work as a specialty engineer. This detailed work was necessary to gain some depth – to understand how things "really work" and the problems that can be encountered when they try to design something. These *Experiences* impact the *Math/Science/General Engineering* and *System's Domain and Operational Context* proficiency areas. Also, many CSEs experienced leading design work early in their careers, which would improve the *Technical Leadership* and *Interpersonal Skills* proficiency areas.
- Half of the CSEs had experienced *System Realization*. Systems engineers who had experience in manufacturing, which falls into *System Realization*, explained that these *Experiences* are valuable because they help engineers understand the practical considerations and issues of implementing a design. Understanding the basic constraints on the common manufacturing techniques was stated as very valuable in improving design work and limiting the need for redesign.
- For *Systems Engineering Management*, all CSEs in the sample were also *Technical Managers*. The related activities: planning, configuration management, decision management, etc. are all part of the CSE position. In general, these types of activities were reported to help in the development of *Technical Leadership*, *Interpersonal Skills,* and *Systems Engineering Discipline* proficiencies.

- The vast majority of CSEs have experienced *Concept Definition* and *System Deployment and Use* (82% and 91%, respectively). This is a higher rate than seen in the general Helix population (50% and 55%, respectively).
- *Concept Definition* includes working directly with stakeholders to identify the problem and "true needs" (as opposed to a stakeholder's assumptions about the right type of solution). Gaining this type of understanding first-hand gives systems engineers the opportunity to improve their understanding of the vision for the system and how it will be used, supporting growth in *System's Domain and Operational Concept* and *Systems Engineering Mi*ndset proficiencies. Communicating directly with customers also enables systems engineers to build their skills not just in general communication, but also in the translation of non-technical information for a technical audience and vice versa. This provides an opportunity for improving *Interpersonal Skills* proficiencies. The majority of CSEs have had these *Experiences* – and often fairly early in their careers –helping them grow as systems engineers.
- Considerably more CSEs started in *System Deployment and Use* than did other senior systems engineers (23% and 10%, respectively). Among CSEs, 60% of those who started in *System Deployment and Use* gained experience in the operation and maintenance of relevant systems as members of the US military. The remaining 40% also worked as operators and maintainers, but *working* in industry. Through these *Experiences*, CSEs had the opportunity to understand how a system should operate, what the common processes and procedures were in relation to a system, and to understand the problems that existing systems have. All of these activities provided opportunities to improve the systems engineer's *System's Domain and Operational Concept* proficiency. They also provide key insights about the overall lifecycle of a system, which can improve *Systems Engineering Discipline* proficiency. All of the CSEs who began their careers in *System Deployment and Use* stated that the understanding of issues that can lead to maintenance problems and issues encountered with operating these systems such as counterintuitive interfaces gave them better insights when they eventually began doing design work. These insights better enabled them to do technical tradeoffs and also helped them to better understand the importance of working through a systems concept of operations (CONOPS) early in the design phase. These *Experiences*, then, can improve their proficiencies in *System's Domain and Operational Concept* and *Systems Engineering Mindset* (*Abstraction* and *Foresight),* as well providing specific insights into lifecycle considerations for *Systems Engineering Discipline*.
- No matter where they started in the systems lifecycle, CSEs cited benefits in later phases they experienced. For example, CSEs starting in testing (*System Realization*, 9%) stated they gained insights into the unintended consequences of certain design decisions and these insights helped them avoid some of these pitfalls when they began design work (*System Definition*). Starting in *Concept Definition* – working on stakeholder needs and CONOPS – provided an opportunity to better understand the "end state" or "big picture" – and this helped keep the system goals in mind during the design process.

In the sample of CSEs, there do not seem to be standard patterns to move through the systems engineering lifecycle, except that starting in *System Design* is most common and those who do not start in system design most commonly next move into *System Design*. The order seems less critical than having a mixture of *Experiences* across the lifecycle and having a mindset that enables systems engineers to draw connections across these *Experiences* to enable understanding and growth.

16.3 Experiences across Systems Engineering Roles

There are multiple types of roles that systems engineers can play within a single position or even a single phase of the systems lifecycle. To better understand how individuals grew into their CSE positions, the roles played by CSEs in the Helix sample prior to their first CSE position, and during their first CSE position were analyzed. All roles played by CSEs throughout their careers, up to the point of their participation in Helix interviews, were also analyzed.

16.3.1 Roles Played Prior to First Chief Systems Engineering Position

Figure 31 provides an overview of the roles played by CSEs prior to their first CSE position, to provide insight into the career paths that helped these individuals become CSEs. It may be noted that at the time of creating this chart, the role of 'Classified Ad' (Sheard 1996) was still being considered, and the role of *Systems Engineering Evangelist* was not yet included.

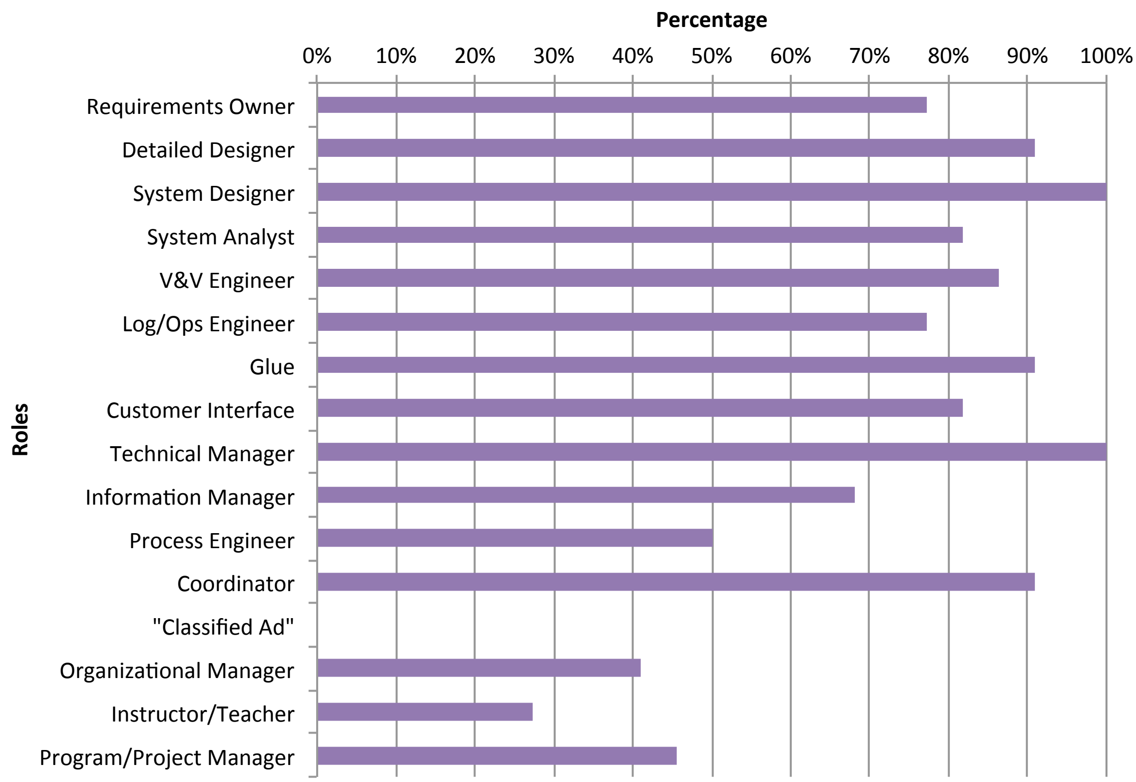


Figure 31. Roles Played by CSEs Prior to Their First CSE Position

Insights from analyzing the roles played by CSEs prior to their first CSE position include:

- All of the systems engineers who would become CSEs worked as *System Designers* and *Technical Managers* prior to their first CSE position. As discussed earlier, these roles are generally a critical aspect of the CSE position, so it is reasonable that individuals would have to prove their abilities in other roles prior to being offered a CSE position.
- The less common roles (50% or lower) are *Process Engineer*, *Organizational Manager*,

Instructor/Teacher, and *Program/Project Manager*. It is possible that CSEs did work in these areas, but this simply did not make it into their descriptions or discussions of the positions they've played.

- The roles of *Organizational Manager*, *Instructor/Teacher*, and *Program/Project Manager* are generally less common in the Helix sample (26%, 10%, and 15%, respectively). The rates among CSEs are more than twice that seen in the general sample.
- One CSE stated that he had performed the *Organizational Manager* role as a favor to the organization – to fill a role that was needed as an interim measure – but with the expectation that he would then pursue a technical track. Other CSEs explained that in their organizations, spending some time as an *Organizational Manager* is a requirement before one can become a CSE. Time spent as an *Organizational Manager* primarily provides insights into the functioning of the organization, and may also provide some insight into processes and opportunities to grow a network of experts within an organization, corresponding with growing proficiencies in *Technical Leadership*.
- Over a quarter of the CSEs have been instructors of in-house training or professors at universities focusing on teaching systems engineering or related subjects. These roles improve proficiency in the subject matter not just through the creation of course materials but also through interactions with the students and the application of real-world *Experiences* in an academic setting.
- The role of *Program/Project Manager* has been played by nearly half the CSEs prior to their first CSE position, as in many organizations the *PM* role was considered a role with higher responsibility than that of CSE. In these cases, the CSE acted as a *Program/Project Manager* on a smaller or less complex system before taking on CSE positions on a larger and/or more complex system. CSEs explained that playing this role helped them to better understand not just the technical constraints of a system, but also to build an appreciation for schedule, budgetary, and resource constraints as well as the overall business case for systems development, and also provided the opportunity to understand the customer's perspective in a different way. This role was particularly strong in helping develop proficiency in the *Technical Leadership* area.

The final aspect of the roles of systems engineers is more general than Sheard's twelve roles (1996) and that is the overarching concept of leadership. Each CSE described having several leadership positions early in their careers, starting generally as small group leaders on simple tasks and continually taking on increasing leadership roles throughout their careers. Several of the systems engineering roles described above may have a distinct leadership component. For example, a *Requirements Owner* may start by simply recording requirements in a database, progress to leading a small team to manage the database, then progress to having responsibility for coordinating with the customer (adding the *Customer Interface* role) to generate the best set of requirements while overseeing the team that manages the requirements. These types of patterns – with leadership responsibilities even in more detail-oriented roles – is a common pattern for CSEs, indicating that it is through leadership activities that systems engineers can provide their greatest value.

There were no clear patterns in the order in which CSEs experienced these roles, except that roles such as *Detailed Designer*, *System Analyst*, and *V&V Engineer* were commonly seen earliest in their careers, with roles containing additional scope of responsibility such as *Technical Manager*, *Coordinator*, and *Glue* becoming more common after the first few positions. These roles came earlier in the careers of CSEs than in those of other senior systems engineers, who tended to spend more time in more detail-oriented roles before taking on their first leadership-related positions. Another take-away is that the vast majority of the positions filled by CSEs are multifaceted: they encompass several different systems engineering roles, and this is true from early in their careers.

Among Helix interviewees, it was far more common that multiple roles were played within a single position than that a position included only one type of role. For example, in one organization, a CSE was described as someone who functioned as a *Technical Manager*, *Glue*, *Coordinator* among engineers and mangers, *Customer Interface*, and *Information Manager* at a minimum. The CSEs in the sample held a combined total of 279 positions over their careers; in only 39 of these positions (14%) did the CSE play a single role. Generally, single-role positions were detailed work early in an individual's career, such as working on a requirements database, doing detailed design, or conducting a specific test. When single-role positions occurred later in an individual's career, the roles tended to be *Organizational manager, Instructor/Teacher,* or *Program/Project Manager*.

16.3.2 Role Played during First Chief Systems Engineering Position

The roles described above were those that enabled a systems engineer to grow sufficiently in capability to be offered a first position as CSE. The Helix team then examined the descriptions of the first CSE position provided both in resumes and interview data, and identified the role(s) associated with these positions and their commonality within the sample of CSEs, as shown in Figure 32.

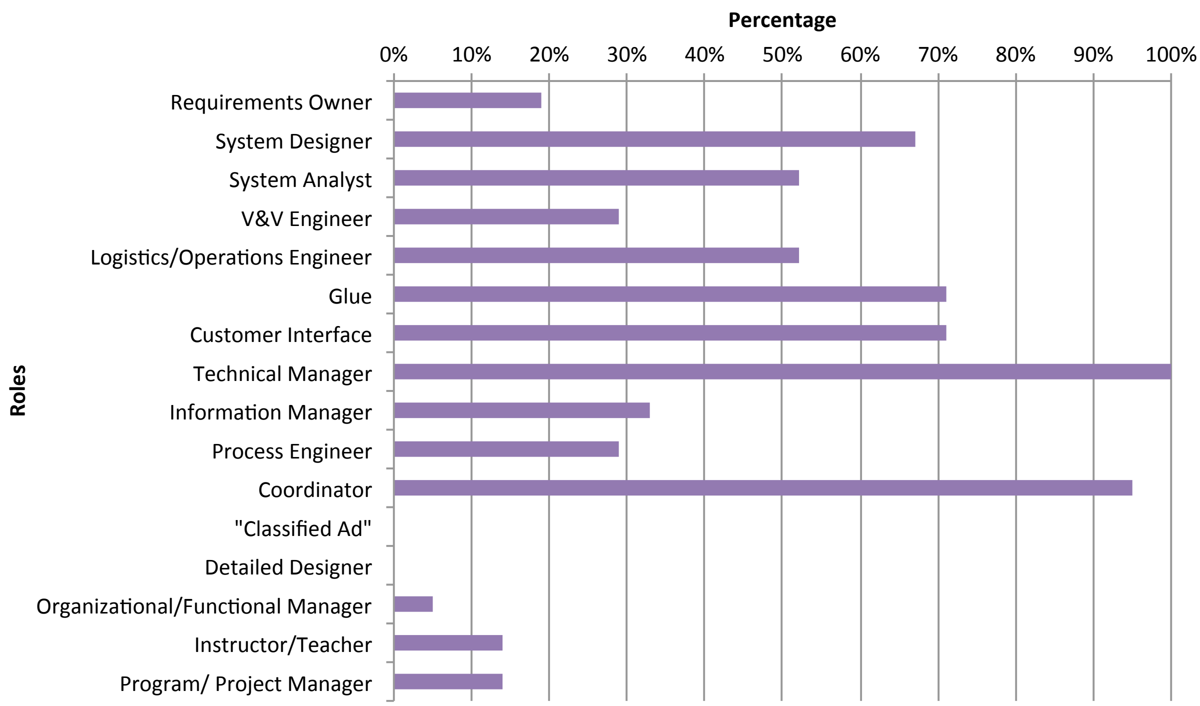


Figure 32. Roles Played by CSEs During Their First CSE Position

Insights from analyzing the roles played by CSEs prior to their first CSE position include:

- All of the CSEs describe the role of *Technical Manager* as a part of the CSE position, and 95% described the role of *Coordinator* as another critical aspect of the position. Over 2/3 of CSEs have had a critical role as *Customer Interface*, *Glue*, and *System Designer* as part of their first CSE position (71%, 71%, and 67%, respectively). One CSE explained that the variety of roles played in the CSE position is somewhat dependent on the organization. For example, when he was a CSE at a small organization, he had to be a "jack of all trades" and therefore played a multitude of roles; now at a much larger organization, his role of CSE is more specialized because there are more people available to perform other roles. Both, he explained, had benefits for development of systems engineering related skills.

- The more detail-oriented roles were less commonly seen as part of the CSE position, but did occur. Often, when a role was not directly performed by the CSE, interviewees explained that the role was simply performed by a member of the team and overseen by the CSE.
- It is fairly uncommon for a CSE to function as an *Instructor/Teacher;* generally, this was explained because a CSE has a wealth of responsibilities and activities and often does not have time to devote to instruction.
- It is also rare for a CSE to function as a *Program/Project Manager*. In the instances where this did occur, it was generally on a smaller project, where the overall smaller staff required that single individuals take on multiple positions.
- *Organizational Manager* is again a very uncommon role for a first CSE position, as the focus for CSEs is generally technical over administrative.
- None of the CSEs had detailed design responsibilities in their initial CSE roles because the CSE must oversee a team of systems engineers and other engineers. Occasionally a CSE would play the role of subject matter expert or detailed designer in a CSE position, but this always occurred much later in their careers, often as part of a smaller project or a proposal.

The roles played in a first CSE position would tend to further proficiencies in *System's Domain and Operational Context*, *Systems Engineering Discipline, Systems Engineering Mindset, Interpersonal Skills*, and *Technical Leadership.* Though a CSE may not lose skills in *Math/Science/General Engineering*, however, because the role(s) played seldom focus on these areas, it would be unlikely for a CSE to gain proficiency in these areas.

Figure 31 and Figure 32 provided insight into the roles played by CSEs up to and including their first CSE positions. Figure 33 provides an overview of the roles played by CSEs throughout their careers, spanning up to their participation in Helix.

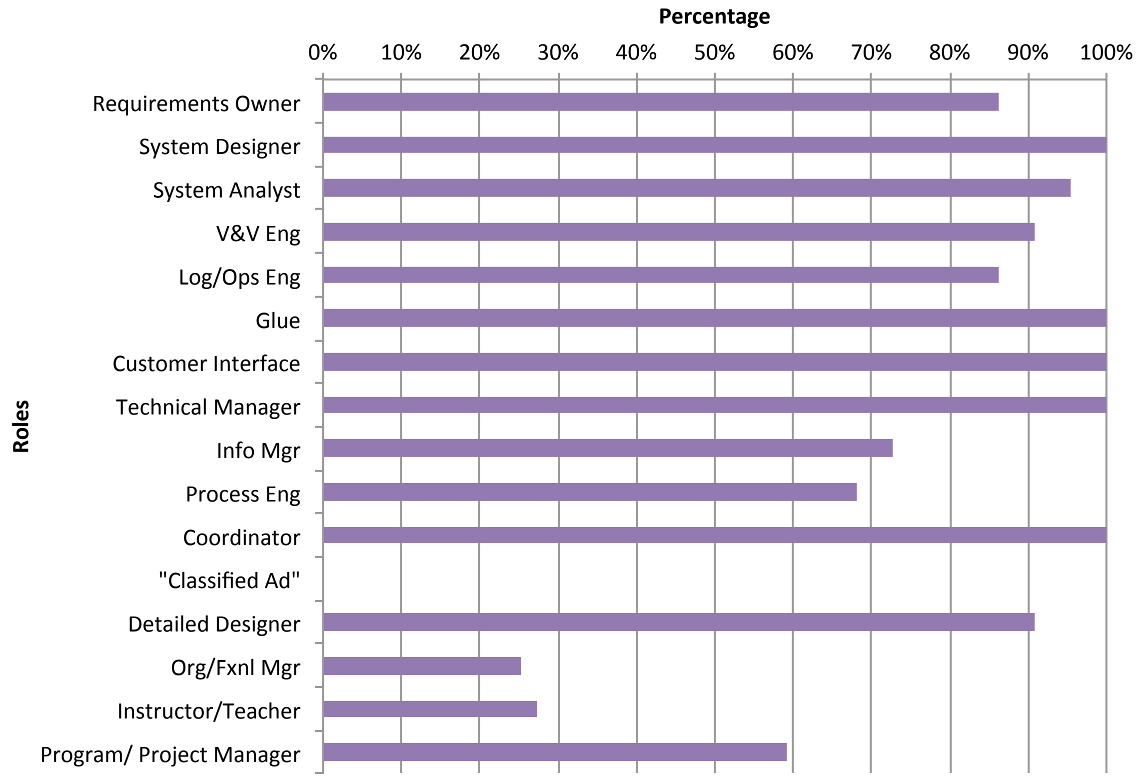


Figure 33. Roles Played by CSEs Throughout Their Whole Careers

The following observations can be made from Figure 33:

- All CSEs in the Helix sample have played the roles of *System Designer*, *Glue*, *Customer Interface*, *Technical Manager*, and *Coordinator*.
- Architecture skills are associated with proficiencies in *Math/Science/General Engineering*, *Systems Engineering Discipline*, *Interpersonal Skills*, and *Technical Leadership*. This provides further insight into the population of CSEs, as 18% have also been the chief architect for a system.
- Even in areas where less than 100% of CSEs have played a role, a much higher percentage of CSEs have played the role than seen in the general Helix sample. For example, 87% of CSEs have played the role of *Requirements Owner* while in the overall Helix sample, this number is just over 40%.

It is clear that the percentage of CSEs who have played these roles continues to rise even after their first CSE position and overall, the percentage of CSEs who have played these roles is considerably higher than in the general Helix population. This indicates that CSEs overall have experiences playing a wider range of roles and that this broad variety of roles continues throughout their careers; it does not stop when they earn the title of "Chief Systems Engineer".

16.4 Insights from INCOSE SEP Analysis

Among the three levels of INCOSE SEP certification, ESEP is the highest category. ESEP applicants are required to submit information of twenty or more years of work history relevant to systems engineering, and are therefore expected to possess significant experience in systems engineering. In the seniority levels defined by Helix, ESEPs that are successfully certified are Senior systems engineers.

As discussed above, analyzing the career paths of CSEs provides some insights for career development. Similarly, within the INCOSE SEP data from certified ESEP applicants, a subset of those who have held a CSE position or a position equivalent to CSE was analyzed. A category called 'ChiefX' was identified, that included certified ESEPs who have held CSE titles or other equivalent titles, specifically, Chief Engineer, Chief Architect, Chief Systems Architect, Chief Principal Engineer, and Chief of Systems Engineering. A comparison of CSEs from the Helix interview data and ChiefXs from INCOSE SEP data was used to partially validate the Helix sample against a larger diverse international sample of systems engineers.

16.4.1 Education of ChiefXs

Table 10 compares the highest degrees obtained by CSEs in the Helix interview data and ChiefXs from the INCOSE SEP data. The highest degrees compare well between the two samples, except that ChiefXs have almost twice the percentage of doctorate degrees than do CSEs.

Table 10. Highest Degree Attained for CSEs (Helix interviewees) and ChiefXs (ESEPs)

Degree Level	CSEs	ChiefXs
Associate's	0%	0%
Bachelor's	23%	23%
Master's	64%	60%
Doctorate	9%	17%

Figure 34 compares the bachelor's degree majors of CSEs and ChiefXs. Electrical engineering comes out as the most popular major in both samples. Though there are some variations, mechanical engineering, computer engineering / science are the next popular majors for ChiefXs. There are some majors such as civil engineering, aerospace or aeronautical engineering, and industrial engineering that are found in one sample but not in the other.

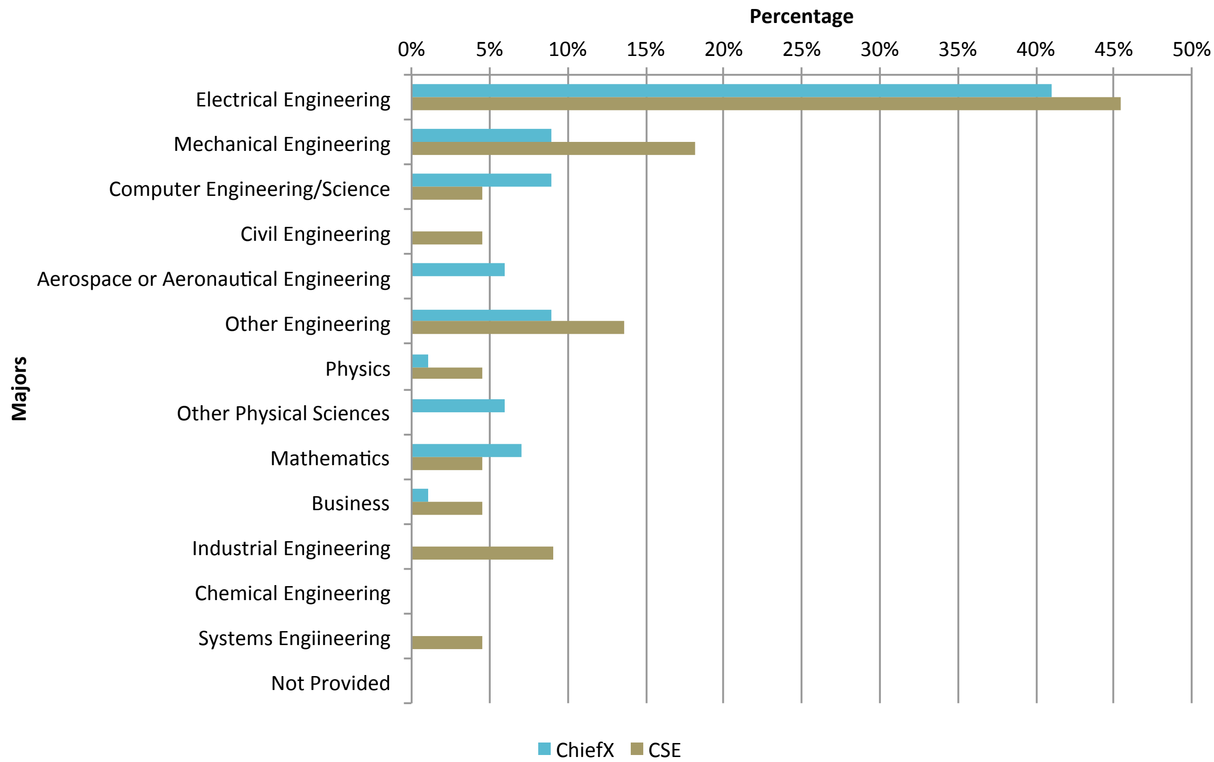


Figure 34. Comparison of Bachelor's Degree Majors between CSEs and ChiefXs

Figure 35 compares the master's degree majors of CSEs and ChiefXs. The most prevalent master's degree major attained was in the area of business – 38% of the CSEs and 39% of the ChiefXs sought a management master's. Most frequently this was an MBA or other management variant. A little less than a quarter of CSEs and ChiefXs pursued a master's in electrical engineering. Almost 10% of CSEs and 13% of ChiefXs complete a master's in systems engineering. The trends observed in master's degree majors indicate similar education profiles for both the CSEs and the ChiefXs.

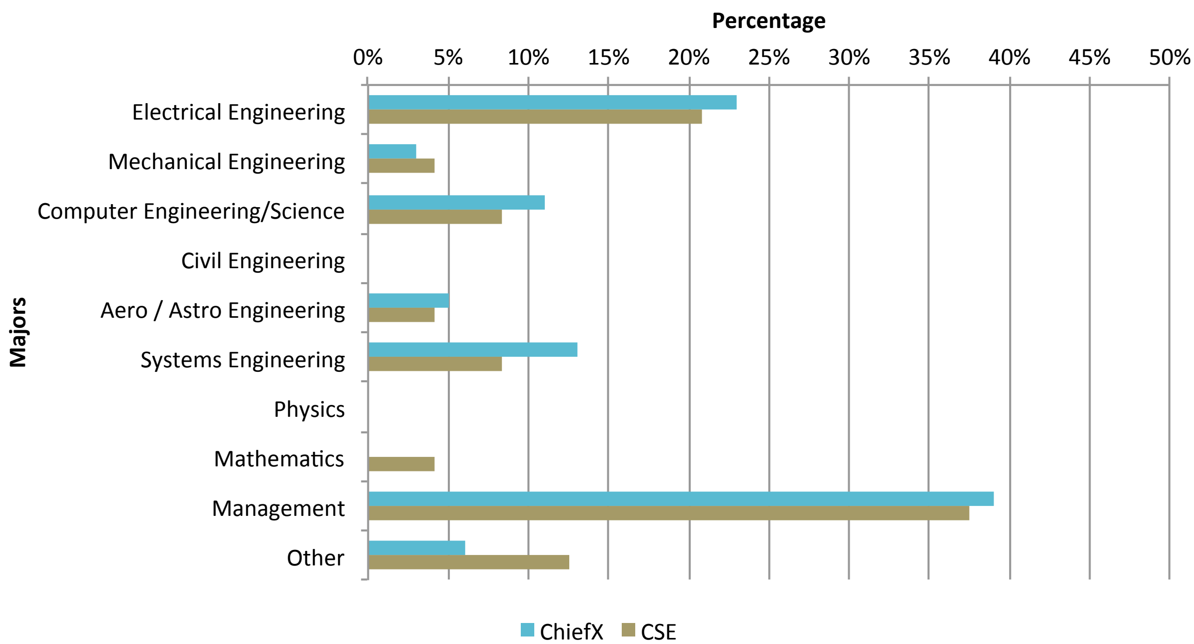


Figure 35. Comparison of Master's Degree Majors between CSEs and ChiefXs

As shown in Table 10, 17% of the ChiefXs have doctorate degrees. This is much greater than in the Helix sample, of which 9% of CSEs have doctorate degrees. Similar to findings from the Helix sample, there was minimal convergence in any specific academic discipline for doctoral study. Of the ChiefXs, 13% of the applicants sought a doctor of philosophy in engineering, mechanical engineering, computer science and systems engineering/integration; the other 4% includes one-off doctorate degrees such as Applied Mechanics and Juris Doctor.

16.4.2 Career Roles played by Certified ESEPs and ChiefXs

Helix identified the *Atlas* roles among INCOSE ESEP applicants, using text-based searches. Figure 36 compares the roles played by senior systems engineers and CSEs from the Helix interview data, compares the roles played by certified ESEPs (non ChiefXs) and ChiefXs from the INCOSE SEP data.

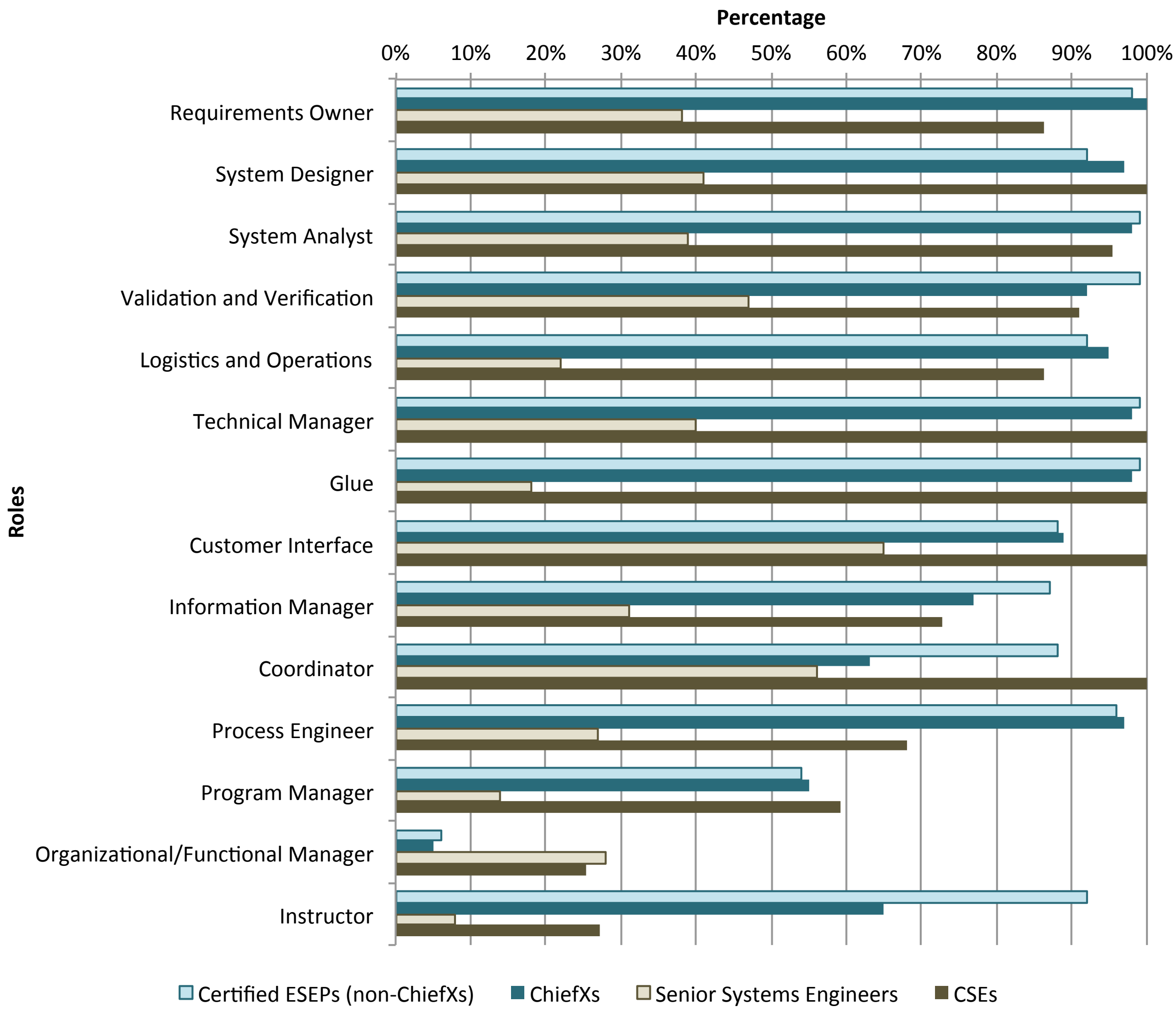


Figure 36. Comparison of Roles Played Throughout Career between Helix Interview Data and INCOSE SEP Data

The career roles played by the INCOSE certified ESEPs and ChiefXs most closely resemble the roles played by the CSEs in the Helix sample. Since INCOSE has an extremely selective process for certifying ESEPs, the individuals that receive the certification have *Experiences* equivalent to the CSEs in the Helix sample rather than the senior systems engineers. Therefore, the senior systems engineers, while they are more seasoned than junior or mid-level systems engineers, do not, in general, have the breadth and depth of *Experiences* in different roles as compared to the CSEs, the ESEPs (non-ChiefXs), and the ChiefXs.

Additional insights include:

- The *Organizational/Functional Manager* role is more common in the Helix interview sample. This could imply that either those who apply for ESEP are more likely to be in a technical track and therefore not have the experience in management to take on this type of role; or ESEP applicants omitted reporting such roles since the application form solicited only systems engineering related tasks and functions.

- The Helix sample identified the most seasoned systems engineers who hold critical systems positions are only occasionally instructors at some point in their career. But in the ESEP applications, the role of instructor is called out more explicitly, and applicants are requested to provide details on training. This may have led to a higher reporting rate among ESEPs than CSEs among Helix interviewees for the role *Instructor*.
- The Helix sample showed that systems engineers often play multiple roles while they are in a single position. This finding was mirrored in the ChiefX subset. More than half of the ChiefXs had compound titles, and therefore it was assumed they were actively performing multiple roles. The most frequent keywords in ChiefX compound titles indicate that organizational leadership is typically a complementary position to CSE. Three of the most frequent keywords in ChiefX compound titles were Manager (17%), Lead (12%), and Director/Head (11%). The other frequent keyword, Architect (8%) indicates that CSEs hold technical and system-specific roles.
- For all ChiefXs who held 3 or more ChiefX titles at some point in their careers (15% of the ChiefX subset), each individual progressed into larger and more complex systems. The Helix sample showed that one common career path for systems engineers' stems from a highly technical position, and through the growth of their careers, the systems engineers take on more responsibility and leadership roles, which correlates with growing of interpersonal skills.

16.4.3 First ChiefX Position Roles

Figure 37 provides a comparison of the roles played by ChiefXs in their first ChiefX position and roles played by CSEs in their first CSE position from the Helix interviewee dataset.

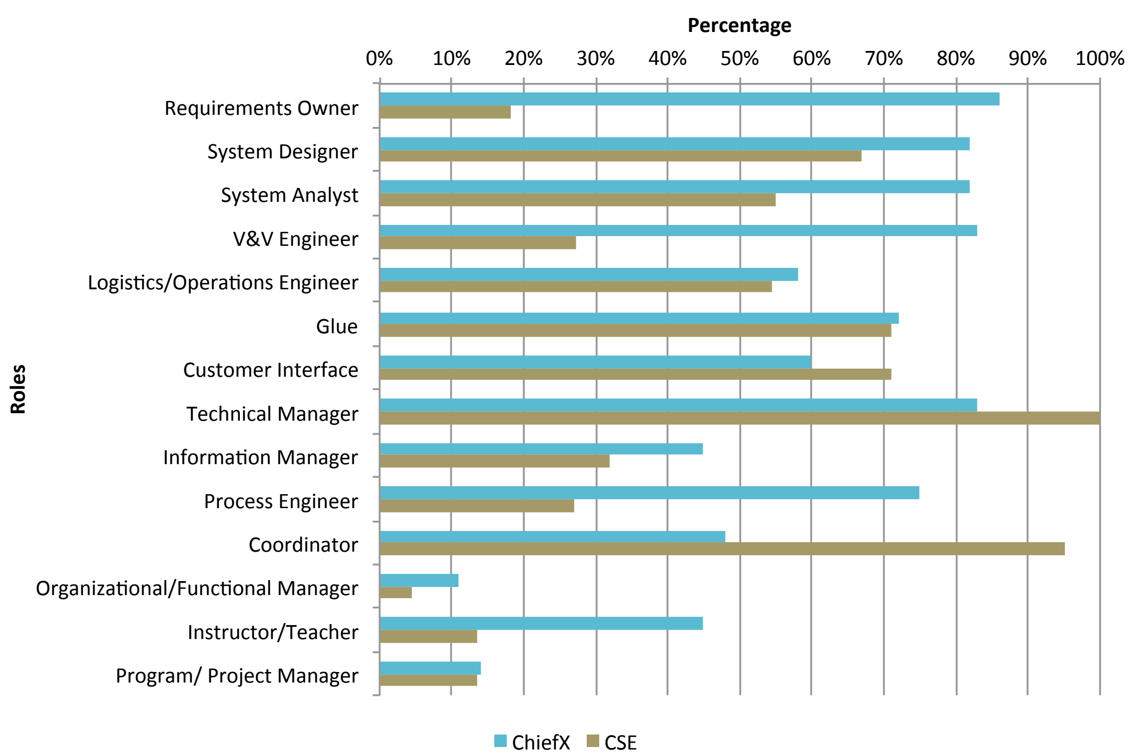


Figure 37. Roles Played in First ChiefX and CSE Positions

As is seen in Figure 37,

- The roles played most commonly during the first ChiefX position are *Requirements Owner*, *Technical Manager*, *Validation and Verification Engineer*, *System Designer*, and *System Analyst*. Conversely, the most frequent roles in the first CSE position are *Technical Manager*, *Coordinator*, *Glue* and *Customer Interface*.
- The CSE sample experienced technical management and programmatic aspects of systems rather than the more technical system lifecycle roles that were experienced by the ChiefXs.
- Almost half (45%) of the ChiefXs played ten or more different roles in their first ChiefX position - 35% played between 5 and 9 roles (inclusive), and 20% played less than 5 roles. Only the *Program Manager* and *Organizational/Functional Manager* roles are performed by less than 40% of the ChiefXs.
- Almost half of the ChiefXs played the role of *Instructor/Teacher* while in their first ChiefX position. This indicates the knowledge base of these individuals, and their willingness to share their critical understanding and experiences with others, ultimately leading to an improvement of their organization.

16.4.4 Value of INCOSE SEP Analysis for Atlas

The INCOSE data was an excellent benchmark for the Helix sample. Characteristics and patterns identified in *Atlas* were further evidenced via comparison of certified ESEPs and ChiefXs with the senior systems engineers and CSEs from the Helix interview sample. There were no major discrepancies that would indicate a need for reassessment of *Atlas*. INCOSE SEP applications provided a wealth of data for use in identifying the *Educatio*n and *Experience* backgrounds of those who have been systems engineers in industry for over 20 years, and are certified as knowledgeable, experienced and accomplished professionals in systems engineering.

17 A Sample Career Path of a Chief Systems Engineer

The position of a Chief Systems Engineer (CSE), or equivalent, is considered to be one of the highest technical positions for a systems engineer, and a framework visualizing a career path was presented in Section 12. The career path of one particular CSE from the Helix data set, 'Athena' (a fictional name) is visualized below in Figure 38.

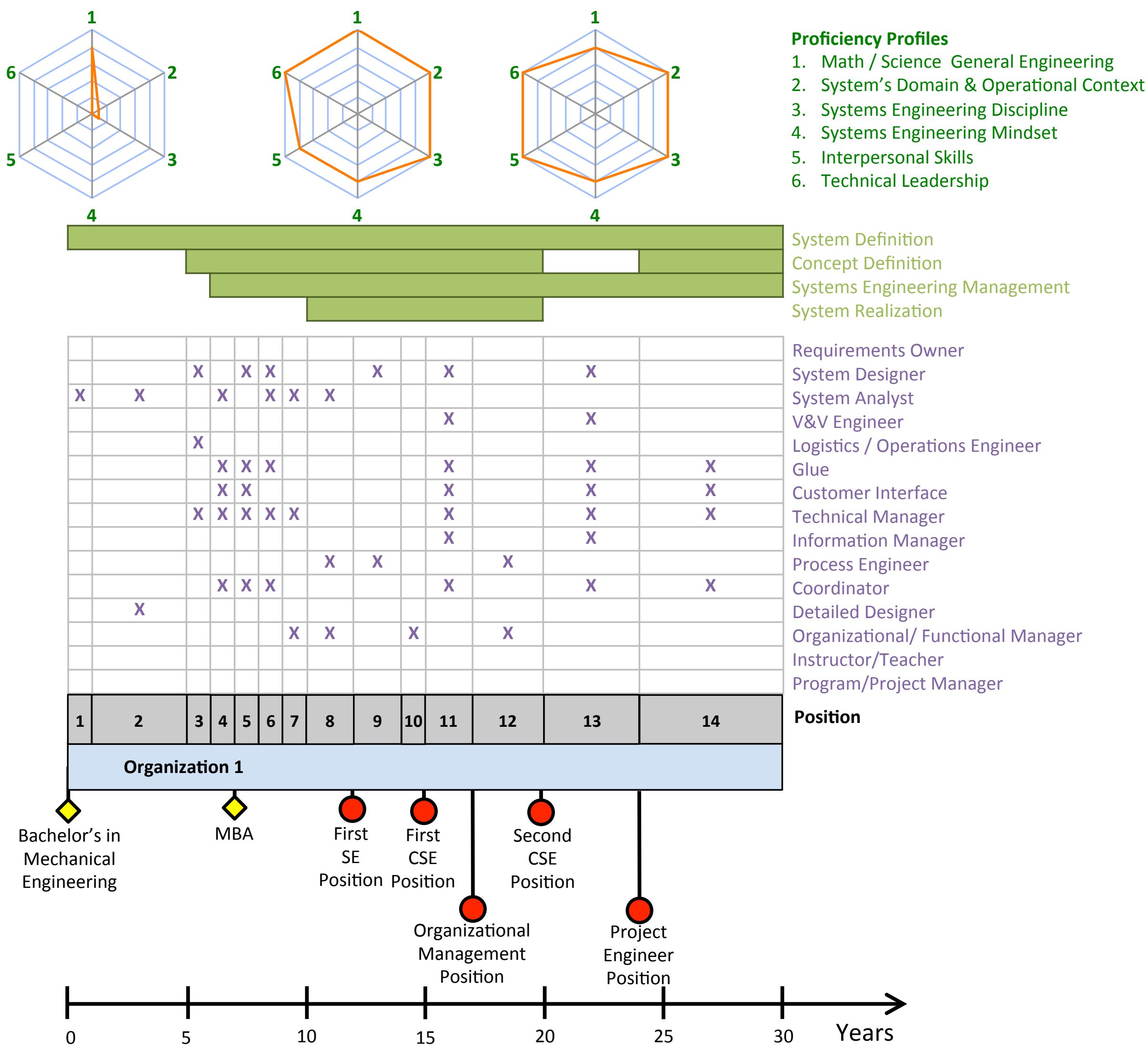


Figure 38. A Sample Career Path

This visualization provides a great deal of insight into Athena's career path. First, it provides detail on Athena's education – a bachelor's degree in mechanical engineering achieved before entering the workforce and an MBA received 7 years into her career. It shows that Athena had a career length of 30 relevant years at the time of her participation in Helix, and Athena had worked in only one organization throughout her career. Within that organization, she had held 14 different positions for varying lengths of time. In terms of key positions, the first formal "systems engineering" position occurred about 12 years into her career and because she is a CSE, the timing of her first CSE position – 15 years – is important as well. Following her first CSE role, Athena became an organizational manager for a few years before taking a second CSE position and then becoming a project engineer. Over half of her career has been spent in formal systems engineering positions and nearly half in senior technical positions (CSE and project engineer).

Above each position, the roles played in that position are detailed; these were identified based upon the description of the positions provided by Athena. These provide further insight not only into what activities Athena was performing at different points in her career but also into the proficiencies she was likely to be developing.

The leftmost proficiency diagram in Figure 38 shows projected proficiency after completion of Athena's bachelor's degree and during her first position. The role played by Athena in her first position was *System Analyst* – specifically applying mathematics, physics, and engineering principles to a real system. The proficiency level for *Math/Science/General Engineering*, therefore, is projected to be higher than what was gained in an undergraduate program. In Position 1, Athena gained *Experiences* working on a specific system within a specific domain, gaining moderate proficiency working in the *System's Domain and Operational Context* proficiency area. She was also exposed to the performance of engineering and tangentially became familiar with the concept of systems engineering and how a system analyst can support systems engineering activities, gaining a moderate proficiency in the *Systems Engineering Discipline* area.

The middle proficiency diagram in Figure 38 shows projected proficiency of Athena going into her first CSE position. By analyzing Athena's first ten positions for the roles played, lifecycle exposure, domain exposure, and types of systems, the projected proficiency would be expected to increase considerably. In fact, going into her first CSE position, Athena would be expected to have "high" proficiency in all areas except *Systems Engineering Mindset* and *Interpersonal Skills*. This is based, again, on the information available on her career path and does not take into account any "baseline" proficiencies. If, for example, Athena was naturally very strong in *Communication* or tended toward *Big-Picture Thinking*, she may have "high" proficiency in these areas, but Figure 38 provides a projection based on what she has had the opportunity to learn based on her *Education* and *Experiences*.

Finally, the rightmost proficiency diagram shows that with additional responsibilities and *Experiences*, Athena maintained her proficiencies. One area that may be surprising is the decrease in proficiency in *Math/Science/General Engineering*. This is because as Athena took on increasing leadership responsibilities, over time she performed less of the detailed engineering or analyses. These skills became less prominent, though were certainly not lost completely. Interestingly, this was a common pattern seen in senior systems engineers. One senior systems engineer explained that he did not need to do detailed engineering or calculations at his level, but he needs to know who can do that work and have a "gut feeling" for whether the answers he receives from those individuals were sensible.

As demonstrated above, the detail provided by analyzing the different elements of a career path provides considerable into proficiency. The type of simple visualization shown in Figure 38 can be created for any combination of the elements of a career path.

18 *ATLAS* DEPLOYMENT – A GLIMPSE

With the publishing *Atlas 0.25* in November 2014, some efforts during 2015 were aimed at gaining an understanding of how *Atlas* might be applied by individuals and organizations. Preliminary versions of assessment tools were created and used during some interview sessions. This section presents some sample results to illustrate some of the ways in which *Atlas* might be used.

18.1 PROFICIENCY EVALUATION – INDIVIDUAL'S PERSPECTIVE

During some of the Helix interviews in 2015, interviewees were asked to self-evaluate their level of proficiency based on the *Atlas* proficiency model, at the Area level. Generally, interviewees evaluated themselves on a level of 1 to 10, where 1 was 'least proficient' and 10 was 'most proficient'. This was a subjective scale and hence when someone placed themselves at an 8 for a proficiency area, for example, it was based on their personal interpretation on what it meant. Helix is developing objective scales for proficiency levels for *Atlas 1.0*. These self-evaluations, based on a 1 to 10 scale and subsequent discussions on why interviewees scored themselves in a particular way, are expected to provide insights towards defining those objective scales.

Interviewees were asked to evaluate their proficiencies at two points in time: (1) at the time of the interview, and (2) at the start of their career. This enables a proficiency profile to be plotted, as illustrated in Figure 39.

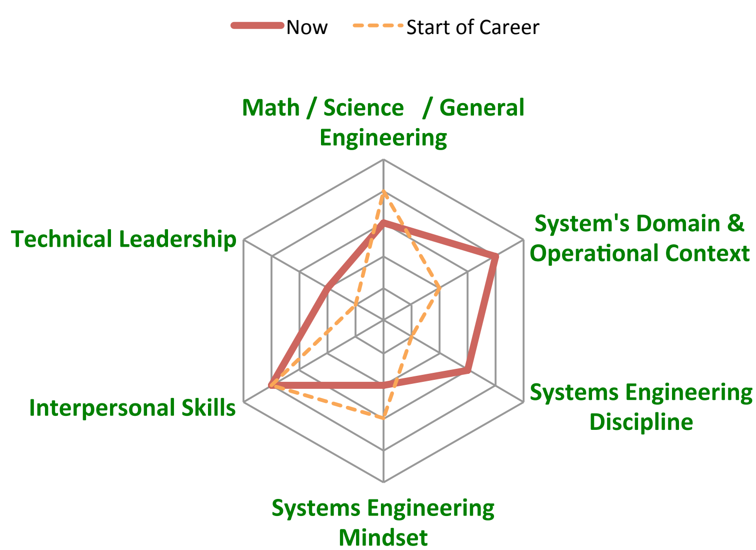


Figure 39. Proficiency Profile of an Individual

The proficiency profile is not meant to be exact since the self-evaluations are subjective, and individuals may have over-evaluated or under-evaluated themselves. Also, 'Start of Career' could be just 5 years ago for one individual and 25 years ago for another. However, this exercise enables a discussion around the relative strengths in specific proficiencies; how proficiency levels changed over time; and what factors or forces caused or enabled those changes.

The primary intent of *Atlas* is not to just understand the current state of effective systems engineers, but to support the development of future systems engineers who will be effective. From a proficiency perspective, it would mean setting target levels for proficiency areas, as illustrated in Figure 40.

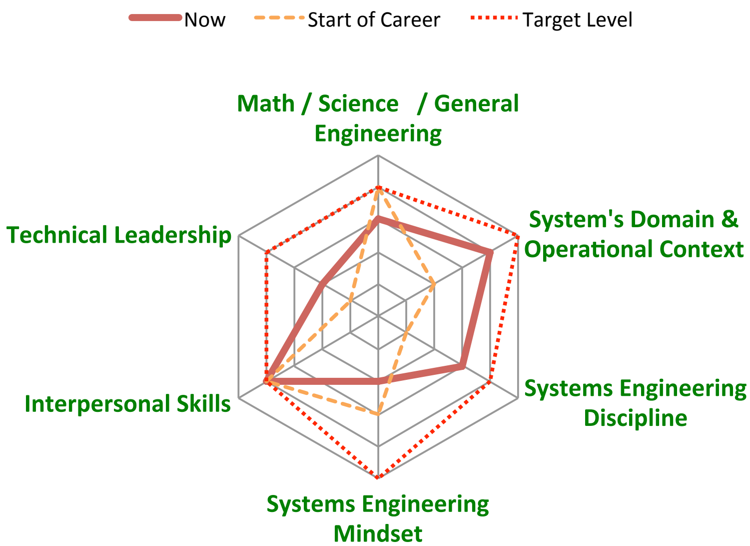


Figure 40. Proficiency Profile with Target Levels

Identifying target levels for the proficiencies will depend on the roles or positions that that individual aspires to play in future. For a junior or mid-level systems engineer, the target level could be based on the proficiency profile of a Chief Systems Engineer. This profile of a CSE is also influenced by the expectations of the organization. Having proficiency profiles, including target levels, similar to what is shown in Figure 40, would enable individuals to identify those proficiencies that need to be developed and by how much. Individual systems engineers could then plan their career development in a more focused and intentional manner, towards a specific goal.

In *Atlas 1.0* (and beyond), Helix intends to provide specific recommendations on which forces are most impactful on which of the *Atlas* proficiencies, by how much, and in what period of time. This will provide valuable insights for individuals on which *Experiences*, *Mentoring*, and *Education & Training* to pursue to support their career goals. Over the last several months, having interviewees perform proficiency self-evaluations and engage in a deeper discussion around the proficiency levels and how the have changed over time, has begun to give Helix the necessary insights to provide recommendations for career development. Figure 41 is based on data obtained from individual proficiency profiles of 20 random systems engineers who participated in Helix interviews in 2015. It shows the change in proficiency levels from the 'Start of Career' to the time of the interview. A positive number indicates the size of increase in the proficiency level in that particular proficiency area, while a negative number indicates the size of decrease in the proficiency level.

	Math / Science / General Engineering	System Domain	Systems Engineering Discipline	Systems Engineering Mindset	Interpersonal Skills	Technical Leadership
#1	2	6	3	-1	2	2
#2	1	5	3	0	2	3
#3	-2	5	6	6	5	7
#4	-4	9	8	4	6	8
#5	2	5	5	6	3	6
#6	-2	6	6	2	2	2
#7	-2	4	6	4	2	4
#8	-1	4	6	0	1	3
#9	0	7	9	0	5	6
#10	1	2	5	2	3	3
#11	-2	4	8	0	2	2
#12	2	6	6	5	4	6
#13	1	3	6	3	3	5
#14	-1	6	7	4	2	6
#15	-1	8	7	3	4	5
#16	2	8	6	3	2	5
#17	1	5	5	3	3	5
#18	-5	5	5	4	4	5
#19	1	5	7	2	3	4
#20	-2	6	5	2	2	7

Scale
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5

Figure 41. Change in Proficiency Levels of Individuals

Figure 41 illustrates a typical distribution of changes in proficiency levels in systems engineers who participated in Helix interviews. Again, the intent is not to perform a detailed quantitative statistical analysis, but to use the information to gather insights for career development:

- The *Math/Science/General Engineering* area is one where many systems engineers said their proficiency levels dropped during their careers. One of the main reasons stated was that they were not using those skills nearly as often (or at all) in their current roles as they did at the start of their careers.
- Systems engineer #4 saw big improvements in the *System Domain*, *SE Discipline*, and *Technical Leadership* areas. Insights into the factors that contributed to those improvements will benefit others who wish to improve those proficiencies.
- Systems engineers #9 and #11 saw big improvements in the *SE Discipline* area, but did not have any change in their level of proficiency in the *SE Mindset* area. Exploring the reasons for this could reveal fresh insights.
- Overall, improvements in the *Interpersonal Skills* area are observed to be relatively modest. It will be useful to explore the reasons behind this.

18.2 Proficiency Evaluation – Organization's Perspective

Developing the career of an individual systems engineer necessitates the concerned individual to make decisions and take required actions. However, they can be done only in the context of the organization. For example, an individual may identify the need for a master's degree in systems engineering as critical to developing some much-needed proficiencies. But if the organization does not encourage or enable its employees to pursue higher education, that systems engineer may not be able to obtain that master's degree while being employed in that organization. Hence, there is a critical role that an organization plays in developing the careers of individual systems engineers.

There are insights that an organization may be able to obtain by studying the collective proficiency profiles of its systems engineers. Figure 42 shows the self-assessment of the same 20 random systems engineers included in Figure 41, for all six of the *Atlas* proficiency areas, highlighting the strongest (green) and weakest (red) proficiency areas.

	Math / Science / General Engineering	System Domain	Systems Engineering Discipline	Systems Engineering Mindset	Interpersonal Skills	Technical Leadership
#1	8	8	7	7	7	7
#2	6	6	4	8	7	7
#3	4	7	7	8	9	9
#4	5	10	8	9	7	8
#5	7	7	5	9	8	6
#6	4	8	8	9	8	8
#7	6	6	8	6	6	6
#8	7	8	8	9	8	9
#9	8	8	9	9	8	7
#10	5	8	9	9	9	8
#11	4	6	8	6	6	6
#12	6	8	8	8	8	8
#13	8	9	8	10	7	7
#14	7	8	8	8	7	6
#15	6	9	8	9	7	8
#16	6	9	7	9	8	7
#17	8	7	8	7	7	8
#18	4	8	7	9	8	8
#19	7	7	9	6	8	9
#20	6	8	9	8	9	9

Figure 42. Strongest and Weakest Proficiencies of Individuals

If the systems engineering population represented in Figure 42 were to belong to a single systems engineering team or group, studying it could help the team or group recognize workforce development issues as well as opportunities as identified below:

- *Math/Science/General Engineering* is the weakest area for most systems engineers. Of greater interest than identifying reasons for this trend is exploring the impacts of this on the organization's systems engineering capability.
- The *SE Mindset* and *SE Discipline* areas are the strongest for many systems engineers, but also the weakest for some. There may be an opportunity here to establish some mentoring initiatives focusing on these proficiency areas.

The *Technical Leadership* area is a mixed bag, with almost equal number of systems engineers saying it is their strongest or weakest proficiency area. Based on further exploration, a training course could be established within the organization focusing on the specific aspects of technical leadership where systems engineers feel they are the weakest.

PART 5

RECOMMENDATIONS AND FUTURE WORK

Part 5 concludes this report on version 0.5 of *Atlas: The Theory of Effective Systems Engineers*.

- Section 19 summarizes key observations from Helix analysis towards building *Atlas*; recommendations from Helix for individuals and organizations are also included.

Section 20 describes the planned future work towards development and release of *Atlas 1.0*.

19 Key Observations and Recommendations from Helix

The data collected during the Helix interviews and additional data from interviewees has been the foundation from which *Atlas* is being built, using a grounded theory-based approach. Analysis of the data has identified themes; from these themes constructs were developed as the elements of *Atlas*. There are many key observations that have been made relative to career development of individual systems engineers and the systems engineering workforce as a whole. Some of the most important observations and recommendations are summarized here.

19.1 Recommendation from Helix for Individuals and Organizations

Senior and mid-level systems engineers were asked to recommend what steps younger systems engineers should take to grow and become more effective. Junior systems engineers were asked what they believed they needed to do personally in order to grow and become more effective. A total of 167 different recommendations have been catalogued by the Helix team, which validated the tenets of *Atlas* and other findings throughout this report. They have been grouped into a series of primary recommendations below, with discussion for the role of individuals and organizations as appropriate for each. Percentages reported below are the percent of total recommendations that address this issue. Note that the percentages do not add up to 100% because some recommendations may touch on multiple areas or address the balance between different areas (for example, the balance between depth and breadth of experiences.)

- **Systems engineers should seek broadening assignments**. Nearly half of the recommendations (47%) focused around the need for individuals to have a wide variety of *Experiences*.
    - *Individuals* should seek opportunities to explore new areas of the lifecycle, perform new roles, become better acquainted with the technologies of the domains, have additional leadership opportunities, or become more familiar with different aspects of the organization. This may be done in the context of formal rotational programs in an organization, or can be done more informally. Most systems engineers generally focused on the need for breadth of *Experiences*, but some recommendations (13%) also focused on the need to balance depth and breadth of *Experiences*. Conversation around depth generally indicated that an individual be able to understand the technologies, components, and interfaces of the system they are working on; have an understanding of the technical work required to create that system; and have enough depth to be able to have good conversations with and earn the respect of other engineers that support that system.
    - The CSEs in the Helix sample all had *Experiences* in four or five of the six areas of the systems lifecycle, all of them experiencing *System Definition*, *System Realization*, and *Systems Engineering Management*. In addition, CSEs had *Experiences* in 11-13 of the identified systems engineering relevant roles. As a general guideline then, systems engineers should seek roles that provide exposure to new aspects of the systems lifecycle or new roles. Another fairly common pattern was to balance breadth in these areas with depth in a single domain or technology area.
    - *Organizations* should enable individuals to obtain these broadening assignments. It was

fairly common for organizations to do this through formal rotational programs. However, concerns were expressed about the structure of rotational programs and the availability of these programs to different parts of the workforce. In general, these programs were only open to younger systems engineers who were new to an organization. In addition, there were concerns about the approach for some programs. In particular, senior systems engineers reported that junior systems engineers who complete these programs are often given the message that they will be leaders of large systems quickly, but due to the lack of availability of these more senior positions and the fact that these individuals are relatively inexperienced, this does not often happen. This can lead to frustration for many junior systems engineers and some will choose to leave the organization.

    - Another option, then, is that organizations can instead create a culture that is more supportive of allowing individuals to move informally between positions to gain this breadth of experiences. In most organizations, this was reported as very dependent on the manager of each individual systems engineer. If organizations agree that this is important, then they should put in place policies that make transitions between positions easier and focus on the overall benefits to the organization of having more effective systems engineers. This will help remove some of the stigma that many junior systems engineers felt was associated with moving between different parts of the organization.

- **Systems engineers should engage in mentoring relationships**. *Mentoring* can play a critical role in helping systems engineers to improve their proficiency.
    - *Individuals* should seek out mentoring relationships with more seasoned systems engineers throughout their careers and regularly engage their mentor in discussions and seek feedback. Likewise, individuals should look for less experienced systems engineers to connect with and, where possible, provide guidance and insight based upon their own experiences.
    - *Organizations* should seek to foster the exchanges generated by mentoring relationships. The Helix data shows that rigid formal mentoring relationships are often less effective than informal ones. However, organizations can encourage mentoring relationships by providing guidance, training, or other resources on how to work in a mentoring relationship; set expectations that senior systems engineers should in general function as mentors; or make engagement in mentoring relationships part of how systems engineers are evaluated.
- **Systems engineers should ask probing questions**. Though a smaller percentage of systems engineers spoke directly about this when asked for recommendations to individuals (8%), this was a theme that emerged in other aspects of the interviews well.
    - *Individuals*, particularly junior systems engineers, should “constantly be asking the ‘why’ questions.” This refers to both technical questions about the system, questions about the decisions made in the past on a system, and about how the organization approaches systems engineering work in general. Senior systems engineers said that often junior systems engineers do not seem empowered to ask these questions, but *they are critically important to developing a big-picture view of both the system and the context of systems development within the organization*. It is important, then, that more senior systems engineers also approach these questions not as challenges to themselves or

their authority, but instead as opportunities to help junior systems engineers improve their overall understanding.

  - *Organizations* should encourage a culture where this type of questioning is seen as a benefit and not a challenge to authority. In addition, organizations could develop some guidelines or history of why business or engineering is done in a certain way. One senior systems engineer stated, "I'm not sure we necessarily give young engineers training and background to say, 'Culturally why our processes are the way they are today is because historically for the last 25 years prior to the last 10 years, that we followed these regimented standards for how to do development efforts to be successful with our customers.' And if we did that more, I think they would understand where they are in the process; they would understand why we do what we do…." This is the type of exchange that could also be encouraged as part of a mentoring relationship.

- **Systems engineers should take advantage of *Education & Training* opportunities** and look for ways to immediately implement their learning in practice. There were a number of systems engineers who believed that *Education & Training* play an important role in development and provided specific recommendations on how to best utilize these growth opportunities (22%). While the details of available training differed between organizations, there were some common themes.
  - *Individuals* should make themselves familiar with the *Education & Training* opportunities offered within an organization and become their own advocates for participating in those programs. In addition, 16% of those who spoke about *Education* specifically highlighted that it is critical for individuals to immediately apply on the job what they learn from *Education & Training*. For example, individuals of the same seniority, working in the same unit of an organization, would often have conflicting views on the usefulness of the same training courses. When asked their rationale, individuals who were able to apply the techniques on the job were far more likely to find the training useful and effective than individuals who felt it did not readily apply to the work they did. Several individuals indicated that in order for the training to become useful, they would have to retake it and then immediately apply it on the job.
  - Though training opportunities varies widely between organizations, graduate education was common and valued in the sample. The most common and commonly recommended master's degrees for systems engineers were a master's degree in systems engineering or an MBA (or other business-related degree). The master's degree in systems engineering provides a holistic overview of the discipline and was valued as a means to improve the *Big-Picture Thinking* for systems engineers, particularly in organizations where rotational assignments were difficult to obtain or where long life cycles made it difficult for systems engineers to gain a more holistic understanding hands-on. MBA degrees provided the business context for many of the engineering decisions, helping individuals to understand how to make technical issues more understandable and important to their organizations.
  - *Organizations* should set policies in place that make it easier for individuals to take advantage of available *Education & Training* opportunities. A common roadblock heard when discussing *Education & Training* was that the organization did not provide sufficient support for training; for example, a course deemed critical may be offered only once a year to a limited number of individuals or managers would consistently

decide that individuals could not have time away from their work to attend courses. While this is an incentive for individuals to become their own advocates, it also highlights the role of the organization to provide adequate opportunities for and support of training initiatives. The costs associated with training were also commonly discussed as issues, with the burdens being felt by individual departments, again limiting opportunities. One senior systems engineer recommended that organizations "can pay overhead costs - in other words, the cost of the trainer to be here; you could pay that off a top-level budget. You don't need to roll that out to individual departmental budgets, which then becomes the purview of the individual managers saying 'well you went to that class last year, so you can't go to one this year because you've used up your budget for two years'."

  - Finally, perhaps the most important thing that organizations can do is take a more strategic approach to *Education & Training*, and particularly matching these opportunities to the ability of individuals to apply what they learn in practice. While individuals should look for opportunities to apply what they gain from education and training, organizations can also provide a better approach to identifying which individuals should attend training based on their ability to apply the concepts in practice, which would improve overall retention and improve the effectiveness of these programs.

- ***Systems engineers must mind their own careers***. Some organizations do have clear career paths for systems engineers, but most do not. Though only 5% of specific recommendations for individuals focused on this topic, it also came across strongly in the mentoring analysis.
  - *Individuals* should take responsibility for their own careers, seeking opportunities for growth and planning next steps. This was also discussed throughout many different aspects of the interviews. Because most organizations do not have clear career guidance for systems engineers, it is necessary for individuals to take responsibility for their own careers. *Mentoring* was often discussed as a useful way for individuals to explore options and choose appropriate next steps.
  - *Organizations* should create basic career guidance for systems engineers. Of the organization-specific recommendations, 11% focused specifically on the lack of guidance available to systems engineers when planning their careers. This guidance could include the types of roles individuals should expect to play at certain stages in their careers and when certain types of training may be most appropriate. Even though individuals should take responsibility for their careers, several senior systems engineers recommended that if organizations could create general principles for systems engineers to follow in their careers, it would greatly support junior systems engineers in making better decisions about which positions to seek.

20 FUTURE DIRECTIONS

During 2016, Helix will largely focus on creating and validating *Atlas 1.0*. There are many tasks that are planned for 2016 that would support development of *Atlas 1.0* and other research extensions. The major directions are:

- **Validating *Atlas***: Being developed using a grounded theory-based approach, *Atlas* is reflective of the data that has informed the building of the theory. Validity of the elements of *Atlas*, particularly of the proficiency model, and the career paths of systems engineers outside the population of the current Helix interviewees is to be established. To support this, validation will be an explicit objective of upcoming Helix site visits.
- **Expanding the Industry Sectors and System Types**: In addition to validation, expanding Helix beyond DoD and DIB is expected to provide new insights into generating the forces and developing the proficiencies identified in *Atlas*. Helix will continue to reach out to commercial organizations from different sectors, and organizations developing different types of systems – in scale, complexity, and domain.
- **Strengthening the Dynamic View of *Atlas***: Career paths of systems engineers capture the dynamic aspect of *Atlas*. This will be further explored in 2016 not only to study the dynamic aspects leading up to the current level of proficiencies of individual systems engineers, but being able to predict future changes in proficiency levels as a result of specific forces. Appropriate modeling tools and simulation techniques will be explored.
- **Supporting Independent Atlas Deployment:** *Atlas 1.0* will not only present a more mature version of the theory of effective systems engineers, it will also provide several of the artifacts needed by individuals and organizations to independently use *Atlas* for personal and workforce development.
- **Engaging on a Large-Scale:** Until now, organizational participation in Helix has been on a small to medium scale in terms of the systems engineers who participated in Helix interviews, compared to the entire systems engineering population within an organization. If presented with the opportunity, Helix anticipates a large-scale engagement of a systems engineering organization in Helix where a significant portion of the systems engineering population will be interviewed or studied in some manner; many of the individuals will not be systems engineers themselves, but interact with systems engineers; and a deeper understanding of the organizational characteristics will be obtained. The results of this large-scale engagement may not readily transfer outside of that organization, but the exercise is expected to validate the anticipated value of *Atlas* to individuals and organizations.
- **Community Building:** Helix workshops will continue to be a forum for various Helix stakeholders to review the progress and plans of Helix; for organizations who have already participated in Helix to share the experiences; for other organizations to share their expectations; and for the systems engineering community art large to set the expectations for Helix that would be most valuable.

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ACRONYMS & ABBREVIATIONS

CSE	Chief Systems Engineer
DASD(SE)	U.S. Deputy Assistant Secretary of Defense for Systems Engineering
DIB	Defense Industrial Base (that supports DoD)
DoD	U.S. Department of Defense
GRCSE	Graduate Reference Curriculum for Systems Engineering
HR	Human Resources
INCOSE	International Council on Systems Engineering
IPT	Integrated Product Team
IR&D	Internal (or Independent) Research & Development
IRB	Internal Review Board
IT	Information Technology
IV&V	Integration, (or Independent) Verification, & Validation
MBA	Master of Business Administration
NDIA-SED	National Defense Industrial Association – Systems Engineering Division
PEO	Program Executive Office
PLM	Product Life Management
QRC	Quick Reaction Capability
SE	Systems Engineering
SERC	Systems Engineering Research Center
SEBoK	*Guide to the Systems Engineering Body of Knowledge*
SME	Subject Matter Expert
SPRDE	Systems Planning, Research, Development, and Engineering
UARC	University-Affiliated Research Center
V&V	Verification & Validation
PM	Project (or Program) Manager